NITED STATES
RTMENT OF
MMERCE
LICATION

NBS MONOGRAPH 113, VOLUME 2

Research and Development in the Computer and Information Sciences

Volume 2. Processing, Storage, and Output Requirements in Information-Processing Systems—A Selective Literature Review

U.S.
RTMENT
OF
MMERCE
National
Bureau
of
andards

NATIONAL BUREAU OF STANDARDS

The National Bureau of Standards [1] was established by an act of Congress March 3, 1901. Today, in addition to serving as the Nation's central measurement laboratory, the Bureau is a principal focal point in the Federal Government for assuring maximum application of the physical and engineering sciences to the advancement of technology in industry and commerce. To this end the Bureau conducts research and provides central national services in four broad program areas. These are: (1) basic measurements and standards, (2) materials measurements and standards, (3) technological measurements and standards, and (4) transfer of technology.

The Bureau comprises the Institute for Basic Standards, the Institute for Materials Research, the Institute for Applied Technology, the Center for Radiation Research, the Center for Computer Sciences and Technology, and the Office for Information Programs.

THE INSTITUTE FOR BASIC STANDARDS provides the central basis within the United States of a complete and consistent system of physical measurement; coordinates that system with measurement systems of other nations; and furnishes essential services leading to accurate and uniform physical measurements throughout the Nation's scientific community, industry, and commerce. The Institute consists of an Office of Measurement Services and the following technical divisions:

Applied Mathematics—Electricity—Metrology—Mechanics—Heat—Atomic and Molecular Physics—Radio Physics [2]—Radio Engineering [2]—Time and Frequency [2]—Astrophysics [2]—Cryogenics.[2]

THE INSTITUTE FOR MATERIALS RESEARCH conducts materials research leading to improved methods of measurement standards, and data on the properties of well-characterized materials needed by industry, commerce, educational institutions, and Government; develops, produces, and distributes standard reference materials; relates the physical and chemical properties of materials to their behavior and their interaction with their environments; and provides advisory and research services to other Government agencies. The Institute consists of an Office of Standard Reference Materials and the following divisions:

Analytical Chemistry—Polymers—Metallurgy—Inorganic Materials—Physical Chemistry.

THE INSTITUTE FOR APPLIED TECHNOLOGY provides technical services to promote the use of available technology and to facilitate technological innovation in industry and Government; cooperates with public and private organizations in the development of technological standards, and test methodologies; and provides advisory and research services for Federal, state, and local government agencies. The Institute consists of the following technical divisions and offices:

Engineering Standards—Weights and Measures — Invention and Innovation — Vehicle Systems Research—Product Evaluation—Building Research—Instrument Shops—Measurement Engineering—Electronic Technology—Technical Analysis.

THE CENTER FOR RADIATION RESEARCH engages in research, measurement, and application of radiation to the solution of Bureau mission problems and the problems of other agencies and institutions. The Center consists of the following divisions:

Reactor Radiation—Linac Radiation—Nuclear Radiation—Applied Radiation.

THE CENTER FOR COMPUTER SCIENCES AND TECHNOLOGY conducts research and provides technical services designed to aid Government agencies in the selection, acquisition, and effective use of automatic data processing equipment; and serves as the principal focus for the development of Federal standards for automatic data processing equipment, techniques, and computer languages. The Center consists of the following offices and divisions:

Information Processing Standards—Computer Information — Computer Services — Systems Development—Information Processing Technology.

THE OFFICE FOR INFORMATION PROGRAMS promotes optimum dissemination and accessibility of scientific information generated within NBS and other agencies of the Federal Government; promotes the development of the National Standard Reference Data System and a system of information analysis centers dealing with the broader aspects of the National Measurement System, and provides appropriate services to ensure that the NBS staff has optimum accessibility to the scientific information of the world. The Office consists of the following organizational units:

Office of Standard Reference Data—Clearinghouse for Federal Scientific and Technical Information [3]—Office of Technical Information and Publications—Library—Office of Public Information—Office of International Relations.

---

[1] Headquarters and Laboratories at Gaithersburg, Maryland, unless otherwise noted; mailing address Washington, D.C. 20234.
[2] Located at Boulder, Colorado 80302.
[3] Located at 5285 Port Royal Road, Springfield, Virginia 22151.

UNITED STATES DEPARTMENT OF COMMERCE • Maurice H. Stans, *Secretary*
NATIONAL BUREAU OF STANDARDS • Lewis M. Branscomb, *Director*

Research and Development in the Computer and Information Sciences

2. Processing, Storage, and Output Requirements in Information Processing Systems: A Selective Literature Review

Mary Elizabeth Stevens

Center for Computer Sciences and Technology
National Bureau of Standards
Washington, D.C. 20234

t.
U. S. National Bureau of Standards, Monograph 113, Vol. 2

Nat. Bur. Stand. (U.S.), Monogr. 113 Vol. 2, 125 pages (May 1970)

CODEN: NBSMA

Issued May 1970

For sale by the Superintendent of Documents, U.S. Government Printing Office
Washington, D.C. 20402 (Order by SD Catalog No. C13.44:113/Vol. 2), Price $1.25.

Library of Congress Catalog Card No. 70-603263

Foreword

The Center for Computer Sciences and Technology of the National Bureau of Standards has responsibility under the authority of Public Law 89–306 (the Brooks Bill) for automatic data processing standards development, for consultation and technical assistance to Federal agencies, and for supporting research in matters relating to the use of computers in the Federal Government.

This selective literature review is the second in a series intended to improve interchange of information among those engaged in research and development in the fields of the computer and information sciences. Considered in this volume are the specific areas of information processing, storage, and output.

Names and descriptions of specific proprietary devices and equipment have been included for the convenience of the reader, but completeness in this respect is recognized to be impossible. Certain important developments have remained proprietary or have not been reported in the open literature; thus major contributors to key developments in the field may have been omitted.

The omission of any method or device does not necessarily imply that it is considered unsuitable or unsatisfactory, nor does inclusion of descriptive material on commercially available instruments, products, programs, or processes constitute endorsement.

LEWIS M. BRANSCOMB, *Director*

Contents

Figures

Research and Development in the Computer and Information Sciences

2. Processing, Storage, and Output Requirements in Information Processing Systems: A Selective Literature Review

Mary Elizabeth Stevens

Areas of concern with respect to processing, storage, and output requirements of a generalized information processing system are considered. Special emphasis is placed on multiple-access systems. Problems of system management and control are discussed, including hierarchies of storage levels. Facsimile, digital, and mass random access storage media and techniques are considered. A variety of output mode requirements are also considered, including direct recording to microforms; on-line display systems; printing, photocomposition, and automatic character generation; and three-dimensional, color, and other special-purpose display systems. Problems of system use and evaluation are also briefly noted. A bibliography of approximately 480 cited references is included, together with supplemental notes and quotations from the literature.

Key words: Computer-assisted-instruction; information display; information recording; machine-aided design; memory allocation; microforms; multiple-access systems; on-line systems; output modes; photocomposition and typesetting; storage hierarchies; time sharing.

1. Introduction

This is the second in a series of reports concerned with research and development requirements and areas of continuing concern in the computer and information sciences and technologies. In the first report of this series, "Information Acquisition, Sensing, and Input: A Selective Literature Review," background considerations and general purposes intended to be served by the series are discussed. In addition, the general plan of attack and certain *caveats* are outlined.* [1.1]

In general, we shall attempt to consider first the areas of research and development concern in the computer sciences and technologies with reference to a schematic diagram of a *generalized* information processing system, as shown in Figure 1.[1.2] In the first report of the series, we considered various implications of Boxes 1, 2, and 3 in Figure 1. In this report, we are concerned primarily with some of the R & D implications involved in the receipt of processing service requests from clients of the system and in the management of the processing operations themselves (especially in terms of multiple-access systems), with efficient and economical storage, with output considerations, and with post-processing operations on output.

Many hardware, design, and theoretical considerations necessarily arise with respect to the development of processing specifications, matching and processing operations, search and selection, and retrieval. We shall defer most of the aspects of information storage, selection and retrieval systems for discussion in later reports in this series. In this report, we will concentrate first on certain aspects of processor system planning and management requirements, with particular reference to multiple-access systems. It is noted, however, that priority scheduling requirements, precedence interrupts, and the like, are as apt to apply to a batch-job system as to one that is operated in an on-line conversational-mode. (See, for example, Nicholson and Pullen, 1968).**

*Appendix A of this report contains notes and quotations pertinent to the running text. For the convenience of the reader, Notes "1.1" and "1.2" in Appendix A recapitulate some of the considerations discussed in the first report.

**See Appendix B for bibliography of references cited in this report.

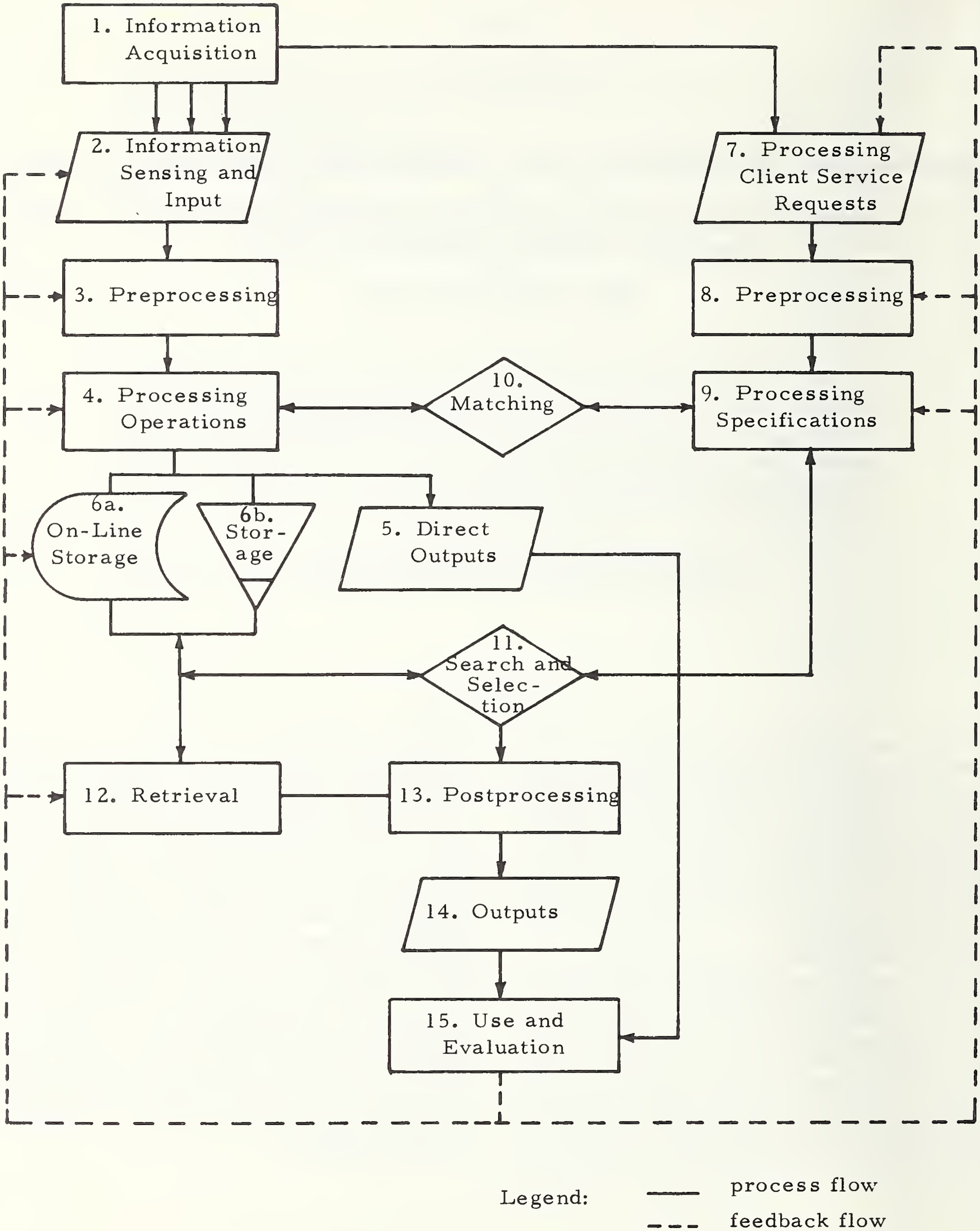

FIGURE 1. *Functional diagram of a generalized information processing system.*

2. Processor System Considerations

Referring to Figure 1, we see that in some cases the processing operations of Box 4 result in direct outputs (Box 5) and/or archival storage (Box 6) as in the case of preservation of input records for subsequent reconstruction if required. In most cases, however, processing service requests are received from clients of the system, from the system itself, or by implications in the incoming data received in Box 2. In parallel with the input data transformations shown in Box 3, we may find reductions or translations of processing service requests to forms or formats that can be processed by the system in Box 8, which may also involve preprocessing operations that are required by priority and scheduling considerations in multiple access systems. Processing specifications developed in Box 9 may be exemplified by controls imposed by measures taken to provide both client and system protection. These specifications, and others, will then be matched (Box 10) to the performance capabilities of the processing system itself and used to control the actual processing operations.

2.1. General Considerations

Processor system planning and management activities must effectively interlace the requirements of multiple inputs of service requests (Box 7), the handling of queuing and job scheduling priorities (Box 8), the provision of suitable means for both client and system protection (Box 9), the requirements of matching the processing service requests to the main processing system capabilities by appropriate supervisory and executive control routines (Boxes 10 and 4), and the orderly flow of both programs and data to and from various levels of storage (Box 6).

In Figure 2 we show those functions of Figure 1 that are most directly involved in the requirements for efficient planning and management of information processing systems as such, together with indications of areas of current and continuing R & D concern. We may consider more particularly here the system design requirements for computer-based multiple access or "time-sharing" systems.

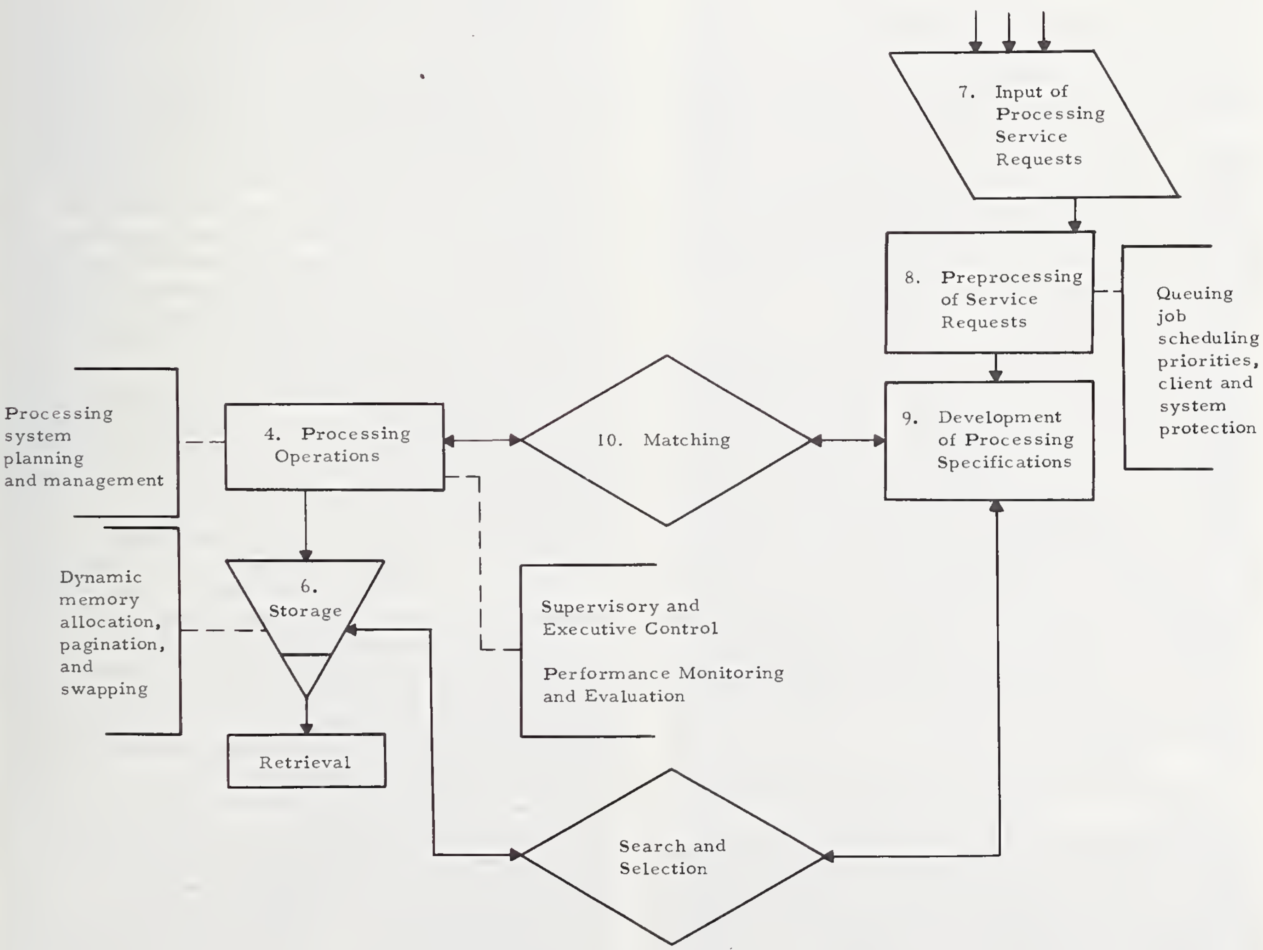

FIGURE 2. *Information processing system management functions.*

"Time-sharing" is the most prevalent and popular terminology for the concept of information processing systems used by many different clients, with effectively simultaneous response to their diversified processing service requests, with at least the apparent effect that the processing facilities are "on-line" to them when they desire to use them and with certain sharing of both data and programs among different users.[2.1]

In fact, some of this terminology is misleading, and the processing system capabilities are not so much shared as divided among many users, with considerable swapping of system resources between them, and with only intermittent access between any individual user and the processor-storage system and its procedures. Thus, we generally prefer to use the more comprehensive term "multiple-access system" to mean "a system in which multiple independent users are provided service by the computer via remote consoles which asynchronously communicate with the computer on a demand basis." (Morenoff and McLean, 1967, p. 19). In general, the systems so-called do not provide *time*-sharing capabilities, but they do offer *system*-sharing capabilities.

2.2. Management of Multiple-Access Systems

Considerable current progress can certainly be shown in the development and experimental use of computer-based multiple-access or "time-shared" systems.[2.1a] Nevertheless, many difficult problems remain, including questions of responsive scheduling, effective monitoring, fail-safe private file or data protection, languages of access, and efficient supervisory control.[2.2] A complex intermixture of hardware, software, and human behavioral factors is typically involved.

It is particularly to be noted that major R & D efforts may be required to implement the diversified functions of man-machine reactive procedures with appropriate degrees of client convenience, system efficiency, and economy.[2.3] Licklider suggests further that "industry has not devoted as much effort to development of devices and techniques for on-line man-computer interaction as it has to development of other classes of computer hardware and software." (Licklider, 1965, p. 66.) Those responsible for R & D program planning in the computer and information sciences should therefore be urgently concerned with the problems raised by the potentials for increasing use of multiple-access systems, generally.

2.2.1. General Considerations and Examples

Phenomenal growth is promised in the use of such multiple-access systems over the next few years.[2.4] Continuing difficulties are predicted, however, with respect to such areas as adequate programming languages, the appropriate design of small inexpensive but versatile consoles for personal use, and the provision of effective privacy and protection facilities. From the system design and management point of view, the challenges are to take an overall planning approach, to look toward the integration of many processes that are now distinct, to seek maximum gains from all multipurpose processing opportunities that are available, and to undertake a drastic rethinking of possible trade-offs between benefits and costs.[2.4a]

Sutherland (1965) eonsiders six varieties of on-line information processing systems: (1) processing control systems, where in manufacturing applications the potentialities range from feedback control to the optimization of profit expectancies; (2) inquiry systems, such as those currently used for airline reservation purposes; (3) specialized on-line systems for specific military applications but also for engineering and design; (4) on-line programming systems; (5) on-line problem-solving systems; and (6) on-line instrumentation designed to bring a better understanding of the interplay of the programs and data within the computer.

As examples of experimental developments and applications of multiple-access systems whose facilities are shared by different users, we may cite first the case of mechanized documentation operations and secondly that of on-line problem-solving. The "reactive typewriter plan", proposed by Mooers at least as early as 1959,[2.5] foresaw not only interlibrary cooperation and interchange of records, but tie-ins to a remotely located library or information center for the individual user as well. Inputs from remotely located typewriters or consoles via teletype, telephone, and other communication links, with or without secondary mode transmission via voice channels, are the heart of remote-access time-sharing systems already in experimental operation.

Among these experimental systems we note in particular those that provide responsive and selective access to files of bibliographic data involving scientific and technical literature. A first example is that of the use of the M.I.T. Compatible Time-Sharing System (CTSS) in Project MAC.[2.6] This has been used both by Kessler and in the experimental SMART system developed by Salton and associates at Harvard.[2.7] Kessler's application involves machine access, in a variety of selection-retrieval modes, to a corpus consisting of bibliographic references to periodical literature in the field of physics. Recent developments include the implementation of a "more-like-this" request feature and a provision for delayed service.[2.8] Brown 1966 describes the use of this system for updating a book on the basic data of plasma physics. For the future, Wooster in a 1968 report proposes the Bibliographic On-Line Organized Knowledge System, or BOOK.

At the System Development Corporation, the Q–32 time-sharing system is used both for experimental application of question-answering procedures to reasonably terse, relatively well-structured data (robbery reports of the Los Angeles Police Department) and for more generalized natural language text processing with respect to the Golden Book children's encyclopedia.[2.9]

The BOLD (*B*ibliographic *O*rganization for *L*ibrary *D*isplay) Project initiated at SDC by Borko, involves a number of user stations equipped with CRT display console, light pen, and teletypewriter. The light pen is used to designate document categories (all members of which are displayed), to specify data to be furnished in hard copy form, and to reject data displayed during document search. The keyboard is used to enter desired author or index tag selection criteria. (Borko, 1965; Carter et al., 1965, pp. 62–63).[2.10]

Lockheed Missiles and Space Company's on-line document reference retrieval system was designed for the in-house report collection of some 100,000 items as covered in the MATICO (*M*achine-*A*ided *T*echnical *I*nformation *C*enter *O*perations) system. Search and retrieval procedures, on-line, are based upon such access points as personal and corporate author names, keywords in title, subject headings as assigned, report and contract numbers, and date of publication.[2.11] Search restrictors such as announcement media may be employed and associational displays of index terms used in the system may also be provided.[2.12]

Further details are provided by Summit (1967), who describes the development of CONVERSE into DIALOG, a system developed to investigate experimentally the effectiveness of a user-directed language designed to provide flexible means for reference retrieval.[2.13] A resource-allocation scheme for this Lockheed multiple-access library reference retrieval system is discussed by Reiter (1967).

Other relatively recent examples include applications at the Moore School of the University of Pennsylvania, such as Project CIDS (*C*hemical *I*nformation *D*ata *S*ystem), which deals with formulas, names and properties of chemical compounds that match a client's query, and Project Vector which provides library information retrieval services;[2.14] an experimental system which has been developed by Bunker Ramo for NASA;[2.15] the augmented catalog of project Intrex[2.15a] and SAFARI, an on-line text processing system at the MITRE Corporation.[2.16] It has already been claimed that "there is a general feeling that on-line retrieval is the next major development in information retrieval, and represents the retrieval system of the future." (Drew et al., 1966, p. 341).

It will be noted that many of the proposed applications of such systems imply on-line problem-solving capabilities on the part of the client in the special case of retrospective literature search.[2.16a] More generally, on-line problem-solving possibilities are claimed to provide one of the most challenging areas for the further improvement and increased use of multiple-access systems.[2.16b]

Such general systems will need to meet system design requirements especially suited to the creative user. They require consideration of the convenience to such clients in learning to use, in using, and in modifying their use of the capabilities offered.[2.17] In particular, such systems may be designed to some extent as 'teaching' machines[2.18] and as systems that provide for "mutual training" of the man and the machine.[2.19] Sutherland suggests that on-line problem-solving systems "will require techniques for pattern recognition, process control, and heuristic programming, and will unite them meaningfully." (1965, p. 9.)

In the general case, however, these potentials are closely related to far-ranging prospects for graphical manipulation and display, especially for applications to machine-aided design operations. These prospects, however, will be considered in a later section of this report (5.1.2). Let us next consider here, then, the preprocessing of client service requests in terms of job scheduling, queuing, and priorities.

2.2.2. Scheduling, Queuing, and Priorities in Multiple-Access Systems

In general, it is noted that "computer time-sharing attempts to phase the simultaneous execution of two or more programs so that the execution of any one of the programs occurs during the natural dormancy period of the others" (Brown, 1965, p. 82) and that, "typically, a particular user's program will be allowed to use a processor for a period of time, will be stopped so that another user's program can run, and then at some later time will be *continued* from the point where it was stopped." (Scherr, 1965, p. 1).[2.19a] It has been appropriately observed that effective time-sharing thus involves time-*slicing*.[2.20]

This is a problem area in which both theoretical assumptions and pragmatic considerations based upon relatively limited experience to date require further detailed investigation and evaluation, experimental exploration of alternatives, and study of the design requirements for judicious balancing of hardware and software contributions to an effective system solution.[2.21]

The responsive scheduling of both client access and job-processing requirements will necessarily involve effective queuing procedures, routing service and priority allocations, and on-line monitoring of system operations (whether or not cost accounting and billing requirements are also involved.) Coffman and Kleinrock provide a 1968 survey of priority policies and scheduling methods in use and, in addition, they discuss some of the means by which various users may try to beat the system. Lampson (1968) notes further problems of management-control enforcement.[2.21a]

Some number of different user-control modes should be typically available. For example, in terms of commerical service-center operations, Adams (1965, p. 487) suggests that: "The scheduling method used in the KEYDATA system . . . allows conversational users to reserve a level of service for minutes or hours at a time and guarantees that they will receive at least the agreed level of services on a minute-by-minute basis." In other situations, clients may wish to control whether their jobs are to be processed by remote batch operations or in a conversational mode.[2.22]

In the EDUNET planning conferences (sponsored by the Inter-University Communications Council), it was pointed out that both priority allocations (including pre-emptive priorities) and reservation mechanisms would be needed in order to assure different classes of users their desired levels of service.[2.23] In particular, Caffrey stressed the following: "Priority is not a simple matter; there are several kinds and issues:

- entry into the system (being able to plug in);
- preferential treatment in the stack or queue;
- quality of response;
- efficiency of operation;
- user-priority vs. job-type priority;
- levels of hardware, including storage capacity." (Brown et al., 1967, p. 214).

Early evidence of R & D concern in many of these areas was presented at the 1963 Fall Joint Computer Conference (Aoki et al., and Critchlow, for example). Of the early JOSS (*J*ohnniac *O*pen-*S*hop *S*ystem) developments, beginning in 1963–1964, Bryan reports that considerable effort was devoted to instrumentation measures to record not only the use of the system as a whole but also the characteristics of usage by different users.[2.23a] Kleinrock (1966) discusses the theory of queues in relation to experience of usage in time-shared computer systems. Some SDC developments include those of Coffman and Kirshnamoorthi (1964), Fine et al. (1966), Krishnamoorthi and Wood (1965) and Totschek (1965).

Where there are many system clients for whom effectively simultaneous access should be provided, appropriate scheduling and queuing provisions must be made. To date, such provisions typically range from first-come-first-served and round-robin arrangements (after a given processing interval, if the first client's problem has not been completed, his programs, data, results to that point, and status and re-start information are transferred out of the active part of the system. Then the processing-service requests and data of the next client in line are swapped in, the system returning to the first client only after all waiting clients have had an equal opportunity for processing service) to procedures based upon considerations of length of running time required (e.g., short jobs first), with or without priority-interrupt considerations.[2.24]

In the latter case, overall system efficiency may have a built-in self-improvement facility through the training or disciplining of the typical client. Scherr (1965, p. 105) suggests that: "it seems that scheduling, if properly executed, could be used to 'mold' the users to some extent by assigning priority on the basis of job type, program size, program running time, user think time, etc., etc. Then the user, in trying to 'beat the system', will tend to conform to the image of what the writers of the scheduling program considered to be the ideal user." Further, "if the scheduling procedure gives low priority to a user's program because of one of its characteristics (e.g., program size), users seem to try to eliminate these 'objectionable' features from their programs and interaction usage."

On-line access scheduling may be arranged on either an *a priori* or a dynamic basis.[2.25] Typical system design and operation questions also arise as to scheduling and queuing with respect to multiple system components and as to the number of multiple components necessary to maintain effective service for the clientele.[2.26]

Areas of specific needs for further R & D investigation include the following types of questions:

(1) Whether the specific time interval (or "quantum") allowed to the active client in the waiting line allows, for most clients, an acceptable delay-tolerance and, at the same time, good system utilization? [2.27]
(2) Whether mean-response-time is a good criterion of either probable client-acceptance or of system utilization? [2.28]
(3) Whether overhead time-and-cost requirements have been effectively assessed? [2.29]
(4) Whether comparison of program sequences and data units is sufficiently systematic to decide which priority choices will best contribute to effective utilization? [2.30]

In general, it has been claimed that "the major issues involved in time management are those of selecting a queue discipline, determining optimum quantum size, and dealing with system overhead." (Schwartz and Weissman, 1967, p. 264.) On-line monitoring, it should be noted, will often be required in order to adjust for different input and service requirements "mixes" and to guard against such phenomena as a number of different clients "getting into phase with each other." [2.31]

Then there is the difficult question of scheduling in multiprocessor, multiprogrammed [2.31a] networks and, more generally, in systems incorporating the concept of the "information processing utility".[2.32] Stanga (1967) discusses the performance advantages developed for the Univac 1108 multiprocessor system in terms of multiple processing units and multiple access paths to a variety of input-output and peripheral storage devices. Manacher (1967) considers the special problems of multiprocessor control in the case of a 'hard' real-time environment—that is, one where there are rigid timing bounds (both start-times and deadlines) upon system performance.

Dennis and Van Horn (1965, pp. 3–4) discuss various major characteristics of multiprogrammed, multiprocessor systems in terms of the following factors: (1) computational processes are run concurrently for more than one user, (2) many processes must share resources in a flexible way, (3) individual processes post widely varying demands for computing resources in the same time period, (4) separate processes make frequent references to common information, and (5) the system itself must be capable of flexible adjustments to changing requirements.

Multiprocessor networks may be required with respect to a large, time-shared, computer-utility system. In particular, such networks may often involve relatively small or relatively inexpensive processors to intercede for and to modify processing requests addressed to the control system.[2.33] Multi-level processors may also be involved in routing, screening, analyzing, and consolidating query and response traffic to and from the various areas and levels of storage.[2.34]

The assurance of such access, effectively on an on-line or "realtime" basis, however, implies a sophisticated supervisory control and monitoring system plan, a flexible system language, and a versatile system execution procedure.[2.34a] Techniques of dynamic swapping, memory allocation and relocation and of pagination are directed, often with a high degree of interdependence, toward solutions of this type of problem.

2.2.3. "Swapping," Dynamic Memory Allocation, and Pagination

With respect to Box 4 of Figure 2, there are shown questions of dynamic memory allocation, pagination, and "swapping". These questions obviously involve highly interdependent relationships with the system design problems that are involved in input-output for multiple user systems, in the servicing of client-submitted processing requests, and in the effective management of hierarchies of storage.[2.35]

We have seen in the case of queuing and scheduling of client interchanges with a multiple-access system that, in accordance with various processing specifications, one client's program is typically run for a certain interval and then replaced by that of the next client to be served. When this occurs, it is necessary to preserve the status of the first client's program, to make way for the requirements of the next client, and, at a later time, to restore the displaced client's program to active operation. This is the process known as "swapping."[2.36]

It is noted that the size of the programs and data sets being interchanged between active and inactive status will have considerable effect upon the efficiency of the swapping process.[2.37] Improved efficiency may result if both programs and data sets are effectively modularized so that only those parts actually needed for the new operation are loaded into main memory.[2.38] For another example, at Wayne State University, Abramowich (1967) considers special problems of central core storage allocation in the case of iterative processes where input data items once chosen are never again needed. At Project MAC, an "onion skin algorithm" is used so that only those parts of memory are dumped as are actually necessary to make room for the incoming program. (Scherr, 1965, p. 36).

The problems of pagination relate in particular to the size of the blocks (or pages) of information that may be swapped between various levels of storage and to the management of transfers of such blocks in terms of processing efficiency. While paging typically relieves the programmer of the need to know and manage the actual physical storage of his programs and data,[2.38a] the size of the available page may be critical.[2.38b] Other problems involve questions of periodic "garbage collection"[2.38c] and of projected time-inactive considerations.[2.38d]

A pioneering approach to these problems in terms of both pagination and of dynamic interchange with respect to both program and data-set accessibility was provided in the system design of Atlas.[2.39] It is noted, in addition, that "pioneering work on the concepts of segmentation and the use of predictive information to control storage allocation was done in connection with project ACSI–MATIC." (Randell and Kuehner, 1968, p. 299). Such problems, in general, continue to occupy the attention of system designers.[2.40] "Since the effectiveness of a system increases as the service facilities are shared, a major goal of future research is a system with multiple access to a vast common structure of data and program procedures; the achievement of multiple access to the computer processors is but a necessary subgoal of this broader objective." (Corbató, "System Requirements . . .", n.d., p. 3).

In addition, hierarchies of storage as physical facts, but of virtually infinite file-memory access from the user's point-of-view, are implied.[2.41] Problems of *dynamic* memory allocation and relocation, of "placement" and "fetching",[2.41a] are thus involved at a number of levels of storage.[2.42] However, many current difficulties are to be noted. For example, Wagner and Granholm state that as of 1965 *no* executive or software system has satisfactorily solved the problems of treating the storage hierarchy as though there were only a single store.[2.43]

In general, dynamic storage allocation techniques are intended to provide flexible means for *anticipating* demand on the part of either the client or the executive control mechanisms of the system itself,[2.44] to optimize the utilization of primary access memory,[2.45] and to provide for the calling up of programs, subroutines, and the data to be processed only when, and to the extent, that these are operationally required.[2.46]

An obvious problem arises in terms of variable data structures with respect to the flow of programs and data to and from the various levels of access.[2.47] Such exchanges need also to be accomplished with minimum delay not only for overall system efficiency but also in terms of client patience with respect to the time-scale of response to his requirements.[2.48]

Specific system design suggestions include the development of special processors operable in parallel with the main system[2.49] and the use of a unified approach to the interlocking problems of allocation, relocation, address indexing, and protection devices.[2.50] Ramamoorthy (1966) discusses "look ahead" considerations with specific reference to multiprogramming situations. Walter and Wallace (1967) discuss problems of program lengths, execution time requirements, average time to

process, and loading times in terms of operations at academic computer centers.

There will be, in addition, need for the most careful analyses of typical requirements for pagination or segmentation both of data blocks and files and of programs, including the use of grouped or clustered pages.[2.51] Again, we must consider and evaluate the most effective lead-times and critical path schedules for foresighted transfers of data and programs between the various levels of storage.[2.51a]

For such reasons, Opler concludes: "the achievement of dynamic flow through hierarchical storage will not be easy. Interdevice channels and control mechanisms must be developed. Requirements for development of control programs will be heavy. The devising of new system analysis and description tools is also required." (Opler, 1965, p. 276).

Evans and Leclerc (1967) claim that interactive response systems are typically mere adaptations of conventional systems and techniques and are thus "far from ideal in many respects". They are therefore concerned with developing improved mechanisms for protection, address mapping and subroutine linkages.

Problems of efficient storage allocations in terms of hierarchies of access and of dynamic flow between levels of storage are interrelated in many ways.[2.52] Nevertheless, while techniques of dynamic storage allocation and pagination as currently available solve certain problems of processor system management and control, they also raise continuing problems of more effective overall system design.[2.53] For example, studies at System Development Corporation have shown that a variety of programs may require "considerable reorganization to operate efficiently in a demand-paging environment." (Fine et al., 1966, p. 11).[2.53a] It may be noted further that "an examination of the 'space-time' product for a program illustrates the dangers of demand paging in unsuitable environments." (Randell and Kuehner, 1968, p. 303).

So, too, there are problems of "pagination constraints". With many of the systems so far designed for dynamic memory relocation applications, the "pages" of either program-control or data constituting fixed-length blocks used for rapid automatic transfer between different levels of storage and processing-access are arbitrarily fixed, perhaps generously. Thus, for many applications, a "page" of say 2,000 machine words is generally adequate for subroutine callup or file subsection processing. However, requirements for certain types of experimental investigations and for many practical graphical data processing operations typically involve the processing of two-dimensional arrays of data for immediate and simultaneous access of areas exceeding fixed pagination limitations.

For example, in the case of a 30,000 + quantized bit scan of a 2 x 2″ photograph, the input may well exceed the limitations of say, a 2,000-computer-word "page". Perhaps the input may be judiciously juggled to fit within a 4-page reserved area (with both programming and processing penalties), but, in other cases, nine of such pages would be required, with even more severe penalties. Beyond this, there is the question of the programming effort and computer processing time necessary to achieve, over pagination boundaries, bit manipulation tests and improvements for the total input image area.

Another area of current difficulty is discussed by Head as follows: "Often such read-in and relocation schemes divide core memory into fixed blocks which form a repository for programs of a standard size. This, of course, forces the programmer to make a rigid segmentation of his program into one or more chunks which will fit into the arbitrarily-defined core blocks at read-in time. In a higher-level language, each statement written by a programmer will produce a fairly large yet unknown number of actual machine instructions. This is almost certain to (1) aggravate the read-in problem by producing a greater total number of instructions than would one-for-one machine coding, and (2) prevent the preplanned division of programs into relocatable segments of standard length." (Head, 1963, p. 40).

Finally we note that continuing R & D concern should be directed to the problems of providing adequate protective devices in multiple-access systems, to be considered next.

2.2.4. Client and System Protection

The R & D problems involved in the general area of development of processing specifications (Box 9 of Figure 2) will be considered in more detail in a later report in this series with respect to the complicated requirements of truly flexible information search, selection and retrieval procedures. Similarly, background considerations for system design involving problems of privacy, confidentiality, or security will be covered in a separate report. However, we may consider here as specialized processing specification requirements the provision of means to protect the system from the client, the client from the system, the system from its own malfunctioning, one client from another, and the client from himself.

Scheduling and priority-interrupt features come first to mind, but at a more advanced stage of system planning and design we need to look at very real requirements of protection from unauthorized access, as well as those of system efficiency.[2.53b]

In particular, multiple-user systems require the provision of adequate protective devices for individually owned files and data banks and programs and "custom" subroutines for *shared* data, programs, and program segments, and for the executive, supervisory control, and accounting programs of the system itself. First is the need to shield the system from inadvertent errors, clumsiness, and unauthorized access on the part of a particular client. Thus, regardless of the degrees of privacy required for different clients, the system itself needs protection. This type of situation is especially acute in situations involving user debugging of new pro-

grams or, even more critically, the insertion of new routines into existing programs.*

Then there are the questions not only of system protection from the user, but also of client protection from the system. We note that in the debugging situation, in particular,[2.53c] programs still under development by some users should not, by error, interfere with procedures being run, simultaneously, for other clients of the system.[2.54]

For the protection of the user from himself, on-line debugging programs require efficient supervisory and monitoring control programs (see, for example, Evans and Darley, 1965). In other cases, a combination of hardware and software techniques may be used. Thus, in a project at the University of Pennsylvania, "a small computer [PDP–5] has been used between the questioner and the central processor to act as a filter, so that before a question gets through to the big computers, it is stated correctly." (Electronics **38,** No. 18, 36 (1965).)

Next, the various clients need reasonable assurance that the material they have stored in the system, both programs and data, will be retained without loss, or that it can be recaptured or restored. However, with respect to this aspect of the protection of the client from the system, it is noted that, for example at Project MAC, while system malfunctions have caused some losses of client programs (and even of data), this experience has not apparently discouraged continued use.[2.55] In Kessler's applications of the M.I.T. system, monitoring programs have been developed to check the continuing integrity of the data on file.[2.56] Typically, the client of a multiple-access system will also require protection from various types of on-line instrumentation techniques.[2.57]

Where several users' programs and/or data are simultaneously held in main memory, adequate measures of mutual memory protection must be employed.[2.58] It is necessary that such measures should be extremely flexible because of the rapidity with which swappings and relocations can occur,[2.59] and multi-level *spheres* of protection may be required.[2.60]

Beyond these questions are the problems of access to *shared* processor-systems and to multiple-use, consolidated program facilities, common-use and centralized data banks. "The most delicate aspect of the operation of a multiple-access system of the MAC type is the responsibility assumed by the system managers with respect to the users' programs and data that are permanently stored in the disc files. Elaborate precautions must be taken to protect the contents of the disc files against malfunctioning of the system, as well as against actions of the individual users." (Fano, 1964, p. 18). Notwithstanding the urgency of these requirements, however, much remains to be done. For example, "in present-day on-line systems, protection among processes performing different tasks is either absent or confined to one level of object processes that run under the egis of a master control program." (Dennis and Glaser, 1965, p. 9).

2.3. System Control and Performance Evaluation

Closely related to the problems of scheduling, dynamic memory management, and protection mechanisms are the questions of effective supervisory control and performance evaluation of systems under various conditions of use.[2.60a] In particular, "the total system should be designed to do its own bookkeeping and accounting functions—keeping track of usage, hours, volumes, times, etc.—both for evaluation of the system and management of costs." (Brown et al., 1967, p. 219).

Concurrently, however, the client "needs control over the generation, revision, naming and execution of his job-oriented processing routines, as well as the storage and retrieval of such processing routines as part of his data base. He needs to be able to manipulate logical and arithmetical operators, planning factors and parameters, models and projections of relevant job-oriented operations." (Bennett et al., 1965, p. 437.)

Special problems of system design and control, including processor and program developments, on-line debugging and instrumentation, and system simulation will be reviewed in another report in this series (on overall system design considerations). We note here, however, that "the burden of establishing proper control procedures falls on the system designer who must in so doing use techniques of information theory, quality control, information redundancy control, error detection and correction, numerical analysis, queuing theory, sampling theory, statistical reliability, data reduction, cross correlation, display theory, decision processes, etc." (Davis, 1964, p. 468). Further, "suitable provisions for performance monitoring, trouble detection, and quality control should be included as part of the system design." (Israel, 1967, p. 203).

Examples of various diagnostic and monitoring systems include QUIK TRAN as used in the interpretive mode,[2.60b] the General Electric GECOS II [General Comprehensive Operating System] programs,[2.60c] the PILOT system at M.I.T.,[2.60d] and a computer "Time Monitor" available from Applied Logic Corporation of Princeton, New Jersey.[2.60e] Hornbuckle (1967) describes a combined hardware/software monitoring system for graphic display applications in the Project Genie time-sharing system of the University of California.

Among the types of system performance factors of interest to system managers or users (or both) are measures of memory, paging, and subrouting activity,[2.61] loop factors and trap activity,[2.62] queue length and work profiles.[2.63] Coggan (1967) suggests other measures as well.[2.64] Randell and Kuehner (1968) stress the significance of the "space-time

*In this case, obviously, the "client" may well be a programmer on the staff of the processing system facility.

product".[2.64a] It is noted that "users very often want to know whether and how many channels or storage areas are available, how many other users there are, whether they can schedule use of the system at predetermined times, how much of their allotted time has been expended, etc." (Caffrey, in Brown et al., 1967, p. 219).

An M.I.T. example is the TTPEEK command "which allows a user to inspect both the allotments and usage of his central processor time, as well as his disc, drum, and tape records." (Corbató, 1967, p. 95). A monitor program described by Fiala (1966) displays for all users the size of programs, priority information, and information as to memory space activity, among other factors.[2.65] However, "it is generally agreed that, constrained by cost, the average response time is the single most objective performance measure to the user at present." (Estrin and Kleinrock, 1967, p. 86).

A simulation program developed by Blunt (1965) dealt primarily with first-come, first-served queue unloading strategy, but consideration was also given to selecting data units with the shortest servicing time, and other factors.[2.66] Other examples in the literature include the studies of Krishnamoorthi and Wood (1965) with respect to a limiting distribution of user congestion and of Kleinrock (1966) involving the use of a queuing theory model for the analysis of sequential processing machines, as well as his 1966 and 1967 theoretical studies of systems.

For his Ph. D. dissertation at UCLA, Coffman (1966) has investigated various stochastic models of multiple and time-shared computing operations. Elsewhere, Coffman and Wood (1966) have reported further on inter-arrival statistics for the SDC system and Coffman and Varian (1968) consider problems of page relocation algorithms.[2.66a] Wilkes (1967) reviews a variety of page turning and related problems.[2.66b] Chang (1966) provides a queuing model for non-priority time-sharing such that queue length and response time and their distributions can be readily estimated. Another theoretical investigation of both round-robin and priority scheduling systems is provided by Shemer (1967).

Then there are studies by Martin and Estrin (1967) showing that *a priori* estimates of computation times for given problems on given systems can be generated by modelling these computations with transitive directed graphs. Other theoretical models are exemplified by Kleinrock's (1967) treatment of time-shared computing facilities as stochastic queuing system under priority service discipline, and with the performance measure based upon the average time spent in the system. Nevertheless, many questions of comparative efficiency remain to be explored.[2.66c]

3. Storage, File Organization, and Associative Memory Requirements

Returning to Figure 2, it is to be noted that the development of efficient and economical storage techniques is the area of continuing R & D concern with respect to Box 6. Many of the specific problems of organization and input of material for storage, questions of file management, digital *versus* facsimile storage, and availability of improved storage media (including microforms) will be covered in other reports in this series (e.g., with respect to the domain of information storage, selection, and retrieval research, or, in the case of advanced developments in storage media, to overall system design considerations). Here, we shall emphasize some of those aspects of information storage functions and techniques that are most closely related to the problems of management and use of multiple-access information processing systems. More particularly, we are concerned here with hierarchies of storage systems, with some of the factors in efficient file organization, and with questions of associative (or "content-addressable") memory requirements.

In general, the processing of large volumes of data to provide varied forms of efficient and economical storage is becoming more and more feasible technically, operationally, and economically. As a consequence, more attention needs to be paid to multilevel representations of the information contents of stored items as well as to suitable hierarchies of access, search, matching, selection, and retrieval procedures.

As of 1968, magnetic core techniques are still the principal media for *main*-computer, rapid-access, information stores. Because of multiple-user demands, as we have seen in the previous section of this report, such "memories" (even although they may have typical capabilities of a million bits storage and cycle times of a microsecond or less), require considerable "swapping" and "pagination" requirements for time-shared, time-slicing usage. However, it is noted that "memory paging, or program segmentation, reduces the size of the main memory but increases that of the bulk storage", (Riley, 1965, p. 74) and that therefore increasing concern should also be directed to the management of such secondary storage. It is further to be noted that the effective management of secondary or auxiliary storage has been a recurrent problem for both system designers and programmers over the years.[3.1]

Efficient and economical storage will involve the interdependence of a number of different factors. Among them are the following:

(1) The development and utilization of storage media at many levels of access, density of of information packing, and storage capacity.[3.2]
(2) The effective organization of multi-level storage in terms of hierarchical access provisions.[3.3]
(3) The effective organization of multi-level storage in terms of parallel processing.

(4) The integrated systems design of programming control, processor capabilities, and storage accessing for dynamic internal memory allocation and relocation.[3.4]

(5) The organization of the file or files at any given level of storage, with due consideration to the most harmonious balancing of maintenance and up-dating,[3.4a] indexing and cross-referencing, multiple copy deposits, statistical data on usage, usage-expectancy factors requirements, and the extent to which typical users require responses at such-and-such thresholds (immediacy of response, comprehensiveness versus pertinency, volume of response).

(7) The provision of useful guides, indexes, delimitors (or restrictors) and identifiers, content-indicating clues, and access-priority scheduling, to various sections, compartments, or stratifications of the file or files.[3.5]

(7) The provision of adequate memory protection devices, including write-protect, read-protect, and overwrite protection.* [3.5a]

3.1. Hierarchies of Storage, Data Compression, and Data Consolidation

Just as dynamic memory allocation is increasingly demanded in processor systems involving multiple-access usage, so dynamic space allocations between levels of storage require a new concentration of system design efforts.[3.6] As of today, conflicting demands of fast access and retrievability on the one hand and of compact and economical storage of very large masses of data and recorded information, on the other hand, dictate compromises based upon multiple levels of storage.[3.7]

The trend toward more versatile and convenient means for man-machine interaction in time-sharing and remotely accessed systems where more than mere text-message processing is desired can be expected to continue its current momentum. New emphases in multiple-access systems planning are therefore being directed toward the problems of providing large capacity data storage banks or files organized in hierarchies of accessibility, especially where different users have differing need-to-know privileges.

It is likely in many potential applications that file organization strategies should be geared to either on-line and multiple-access or to batch operations and/or to suitable admixtures of client-controlled and job-shop-controlled priorities of access and processing. In such circumstances, Benner (1967) considers certain minimal file design considerations involving security, recovery, optimal location/addressing, flexibility for meeting changing requirements, and compatibility with the programming system and language(s).[3.7a]

*See also the separate report in this series on some of the background considerations affecting problems of privacy, confidentiality, or security in information processing systems and networks.

3.1.1. Hierarchical Memory Structure

Hoagland[3.8] notes that hierarchical memory structures, with various levels set by access-time characteristics are needed to balance costs, capacities, and access requirements, that the "main" memory size is tied to processor rate in such way that the faster the latter, the larger and faster the memory must be to keep pace, and that *economical* mass-memory systems represent the key to many new applications.

We envisage, first, hierarchies of storage with appropriate balancing of capacities, access time considerations, and usage-demand probabilities. The total storage facilities would be compartmentalized as appropriate by the various types of data to be stored, by usage considerations, and by other criteria conductive to effective maintenance and manipulation. They would be organized in such way as to enable adaptive change to new or modified processing requirements. An important consideration here is that of the provision of "streaming", or equivalent techniques.[3.9]

Hierarchies of storage, especially those involving large bulk memory devices, also suggest the use of redundant recording techniques for improved random access. For example, if fully adequate techniques for machine translation were available, it is not necessarily the case that significant improvements in either mass storage capacity or speed of access would be required before production use could become practical. First, advantage might be taken of Zipf's law respecting the distribution of word frequency possiblities, to organize a hierarchy of dictionary storage and access. Bowers (1966) discusses as one example a dictionary stored for machine translation applications where perhaps 35 percent of the accesses might be to less than 20 of 100,000 entries. He suggests that "in most cases, some combination of different redundancy fractions for several subsets of the store will achieve the minimum access time." (p. 44)

Again, hierarchies of storage may be used to improve the efficiency of list-processing operations as described, for example, by Cohen of the University of Grenoble (1967). This investigator concludes that the best strategy for selecting the least active pages is that of time of inactivity. (See also Bobrow and Murphy (1967) for discussion of adaptations of the LISP programming system to a two-level store.)

Then there are questions of efficient and economical storage with respect to the items themselves, including compression, truncation, use of the information contained in a record to determine automatically its proper storage address, and use of storage addresses as the surrogates for search and retrieval of the stored item itself.

3.1.2. Data Compression and Consolidation

System organization of central processors and of storage systems can be expected to become increasingly modular, and with maximum provisions for

366-108 O - 70 - 2

compatibility (or at least convertibility) as between large and small system configurations available at different locations. However, we may also consider, with respect to system requirements for efficient and economical storage, not only the problems of hierarchies of access but also those of compression of the data actually to be filed.

A typical instance is that of pictorial data representation. Beyond the photographic (or equivalent) means for full, conservative, input data storage (a copy, microfilm or otherwise, for the facsimile representation of the input item) lie possibilities of reductive transformations.* Here, the continuing R & D requirements with respect to information processing system design involve fact-finding and technical analyses.

In particular, we need to learn whether such reductive storage can be so developed as to provide the appropriate type of reproducibility. A given system may require either reduced facsimile of the original, giving only pre-defined significant features, or an enhanced facsimile eliminating noise or redundancy and emphasizing features such as boundaries and edges, or a complete replica of the initial input image. In other situations, processes of re-computation and re-creation to produce a reasonable reconstruction of the original input may suffice.

We would also look forward to increased use of redundancy eliminating fact-correlations, duplicate checking, and validation techniques applied to items available as input for potential retrieval in order to keep storage requirements within manageable bounds. In addition, as Mooers (1959) has pointed out,[3.10] the achievement of a *minimal redundancy* store is of considerable significance from the client's standpoint and from that of overall system effectiveness. In particular: "The . . . [more compelling] reason to avoid redundancy and filler matter is that putting such matter into the store is not the end of it, if the retrieval system is any good. The text, with all its filler and redundancies will keep coming out of the system, time after time, with a consequent vast waste of human effort that will be continued indefinitely into the future." (pp. 27–28)

The basic procedures for storage in the overall system should obviously be simultaneously effective, efficient, and economical. Effectiveness and economy combined may relate, for example, to storage of textual messages in facsimile-reproducible form but with brief, independently searchable, content-indicia and with appropriate selection-retrieval addresses as typical query-output. Yet many considerations of user-acceptance, user-convenience, availability of suitable microform readers, queuing considerations, and other factors may well affect the economics of the situation.

For example, cost considerations (specifically including considerations of total storage requirements, including those of an archival nature), may well dictate microform storage, yet the effectiveness and efficiency of the system may be lowered because of client low-usage or dissatisfaction with microform outputs generally.[3.10a] The economics of storage for subsequent selection and retrieval of specified items relate then, first, to the costs and problems of storage as such and, secondly but not least as critically, to the problems of *selective* recall and effective utilization. The obvious requirements here are therefore those of effective file organization both for purposes of economical storage and for those of efficient search, selection, and retrieval. Beyond these are possibilities for adaptive reorganizations of the file based upon various types of system feedbacks.

Prywes comments that "file organization, which in the past has been given a secondary position in overall system performance, should instead be the kernel of future systems", and, further, that "the sharing of the information in the common store is technically one of the most demanding, and intellectually the most intricate, functions of the system. Continuous enhancement of this capability must be provided through reindexing and reclassifying the changing organization of the total information." (Prywes, 1966, p. 460).

3.2. Problems of File Organization and Structure

Problems of file organization again involve the need for dynamic memory allocation facilities for the hierarchy of storage systems so that files may be set up in layers of segmentation and be rapidly re-organized according to frequencies of usage. Thus, "the system must have *dynamic memory allocation, alternate forms of data structure*, and a *data management* and *transfer mechanism* so that the same data can be used in all aspects of the problem solution." (Roos, 1965, p. 423).

For whatever purpose machine-searchable files are used (record-keeping, inventory control, documentary-item-surrogate storage, or data-, record-, item-, and fact-retrieval), there is a commonality of three principal kinds of operations upon the files. These three types of file processing are those of file input and organization, file search and selection, and file maintenance and up-dating.[3.10b] An example of multilevel file organization for a dynamic system is provided by ver Hoef (1966) with respect to the INTIPS (*Int*egrated *I*nformation *P*rocessing *S*ystem) of the Rome Air Development Center.[3.10c]

The design of effective file organizations will involve first the consideration of the levels of storage required in terms of items of different size and of different type. Similarly, consideration should be given to frequencies of estimated usage. This may take the form of either activity analysis [3.11] or of estimates based upon the age, currency or likely usefulness of items stored in the file.[3.12] Possible self-adaptive features should also be considered.

*See also Section 3.4 of the first report in this series, Information Acquisition, Sensing, and Input.

In particular, file organization must be capable of changing in response to changes in needs for information and also in response to both qualitative and quantitative changes in the contents of the file. There exists therefore a requirement to explore concepts and techniques that will make feasible self-adaptive features in both file organization and in search strategy. (J. Blum and J. Guy, private communication).

There is a wide variety of alternatives with respect to different methods of file organization, whether these are planned with reference to most efficient storage-retrieval operations or whether they are designed with reference to presumed search-selective effectiveness. We may find relatively random file organizations or arbitrary orderings of the records to be stored in the file; for example, in libraries or document collections, by physical dimensions of the stored items, by date of accession, by age class, by journal volume identification, and the like.

Partially arbitrary orderings of the files may be imposed in the form of alphabetical sequences of stored items by their source or author, or by whether or not they fall within certain prescribed chronological time periods, as in many typical correspondence files. Then, in the case of uneven file distributions as determined by continuing activity analysis, there are possible random orderings based upon such assumptions as the following: "The generally accepted solution is to pick a storage location capacity (bucket), which tends to make overflows likely and empty buckets rare. The storage method then goes on to dispose of the overflows by a second rule, e.g., chaining, storing overflow addresses in the bucket, or by assignment to another area." (Dumey, 1965, pp. 258–259).

Hierarchically ordered files typically involve classification schemes and structures of various types and, where it is not possible to determine an exclusive classification for a stored item, the use of cross-reference techniques including the placement of multiple copies of a particular item under several different classification categories, thus providing multiple parallel access to different sections of the file. This is the practice, for example, not only in the hard copy files of the U.S. Patent Office, but in microform storage and retrieval systems such as the Eastman Kodak Minicard developments.[3.12a]

In the case of a partially ordered file organization, there are frequently to be found broad groupings of stored items with perhaps random or arbitrary orderings within each group (e.g., a "bin" approach) or orderings by frequency of usage and the like. The latter type of organization is designed to be particularly responsive to a specific clientele or usage environment.[3.13]

Next to be considered in generalized information processing system design and use are problems of input-output with respect to the files involving considerations of volume and processing time requirements and questions of efficient space allocation and utilization. Then there are problems of whether new material may be substituted for or used to replace other material in whole or in part, updating problems generally, and questions of whether incoming items require transcriptions, re-recordings, encodings, reductive transformations of various types, or reproduction as microforms, and the like.

A special problem with respect to efficient and economical storage of items to be searched and retrieved is that of the encoding of pictorial and graphic information for compact storage, but with full-scale facsimile reproduction capabilities available upon demand. In this area of pictorial data coding, a special case is that of two- or three-dimensional representations of chemical structure information. As has been noted in the first report in this series, (on information acquisition, sensing, and input) a number of coding, ciphering, and notation schemes have been under development for *linear* representations of such structural data in machine-useful form.

Holm (1965) notes that: "Much work is under way to store pictorial representation, such as the chemical structure, in packed coded or binary form, with the reproduction of the original pictorial form upon request either as a display on film, or printed." However, other pictorial data, such as photographs, may probably be stored most efficiently in their original form, in reduced facsimile such as microform, or as TV recordings.[3.14]

Other design requirements relate to problems of access to physical storage and to withdrawals and replacements of items to and from the store. There are maintenance problems including questions of whether or not the integrity of the files must be maintained (i.e., a master copy of each original item accessible at all times), and whether provisions should be made for the periodic purging of obsolete items and revisions of the file organization in accordance with changing patterns of usage or response requirements.[3.14a] Other design questions relate to requirements for display of all or part of an item and/or indications of its characteristics prior to physical retrieval.

With respect to storage media and equipment considerations, the information processing system designer must not only be concerned with the characteristics of materials suitable for storing information (to be discussed in another report in this series, on overall system design requirements), but also with those characteristics affecting the selected methodology of file organization and the total system design. For example, he must carefully consider the interaction between such variables as the size of the file, its organization, the search strategy or strategies to be used, and equipment speed. (See Blunt, 1965, p. 14).

We shall return to these and other R & D considerations in other reports in this series when we discuss the more specialized problems of information storage, selection, and retrieval systems as such, but we note here that many levels of file organization and file compartmentalization may be

used to speed search processes, to conduct multiple searches in parallel, and the like. In particular, data bank management design requirements create file organization problems of increasing severity.[3.14b] In general, where there are increasing opportunities for the establishment and multiple-access use of large-scale data banks, there are increasingly difficult R & D problems in file organization, file maintenance, and file protection.

As Orchard-Hays has emphasized: "Probably the knottiest problem facing system designers today is how to set up, maintain, control and protect huge libraries of heterogeneous data, all changing at different rates and in different ways . . . It is clear that the systems designs of the past are entirely inadequate . . ." (Orchard-Hays, 1965, p. 240). Moreover, it is claimed that "unfortunately little research has been done on methods of organizing and structuring large files. As a result, the available concepts are primitive. One principle is clear: our needs for information are changing; therefore, our file organization must be capable of changing." (Borko, 1965, p. 24).

3.3. Associative Memory Considerations

The concept of associative or content-addressable memories [3.15] has been hailed for well over a decade [3.16] as the potential panacea for many interlocking, multiple-aspect processing problems, specifically including those of information storage, selection and retrieval systems.[3.17] As of 1967–1968, however, little practical realization has been achieved except on a very small scale [3.18] and some observers predict that this condition will continue for some time to come.[3.18a]

Large-scale associative memories have, on the other hand, been simulated on computers, notably in Fuller's 1963 dissertation investigations,[3.19] at the Moore School by Prywes and associates,[3.20] by Landauer [3.20a] and by Feldman.[3.21] In particular, Prywes and Gray (1963) claim that the use of an addressable memory to carry out an associative memory scheme provides a flexibility that would be difficult to achieve with built-in associative hardware.

In a 1967 state-of-the-art review, Minker and Sable comment: "It was refreshing to see the Government support studies leading to quantitative results in the study of hardware vs. software implementation of associative memories. We note that these studies did not show the hardware associative memories to be significantly advantageous. Additional quantitative studies are needed to define the types of problems for which hardware associative memories of various sizes could be useful." (Minker and Sable, 1967, p. 151).

The following desiderata, however, are indicative of continuing R & D concern with respect to memory system design: "Features of the memory structure desirable for a complex processing system are listed below:

1. The number of different lists of items of information, length of lists, and length of information of the item in the memory should be perfectly flexible (except for the total memory size).
2. It should be possible to add, delete, insert and rearrange items of information in a list at any time and in any way . . .
3. The nature of the items in a list should not be restricted. An item may be a symbol, a number, a combination of both in any length or an arbitrary list.
4. It should be possible for the same item to appear on any number of lists simultaneously." (Hormann, 1960, p. 4).

The area of "associative" or "content-addressable" memories will thus require considerable further R & D effort in both hardware and software, including new approaches to file organization.

Starting on the software side, we note the emergence of *list-processing* languages intended to facilitate symbol manipulation directly and thereby problem-solving activities more generally.[3.22] Limitations with respect to multiply-associated data have led to variations involving threaded-lists, inverted lists, and multilist program structures,[3.23] and special systems such as Rover.[3.24] A deliberate attempt to compromise between fixed file organization and list-processing techniques, providing for the building of associative sublists if and only if needed, was indicated in the relatively early NBS model of "selective recall". (Stevens, 1960).

For multiply-related, multiply-associated data in a large file, the problems of efficient storage, selection, and access may involve considerable emphasis upon formal modellings of the possible system parameters and configurations. Here, considerations of efficient machine manipulations of graph-theoretic techniques, input-output economics in the most general sense, control system theory, and studies of the problems of aggregation and partial aggregation may have considerable pertinence.

New technologically-feasible approaches to truly massive direct access file media and to file structurings of the associative memory type point to significant alleviation of some of these problems in the not too distant future. On the other hand, it is not yet clear that enough is now known about multiply-related and associated data to establish organizational schemas that would take best advantage of these promised technological advantages. Other questions as yet largely unresolved include those of the development of performance measures adequate to depict the appropriate trade-offs between storage economy and selection and retrieval effectiveness for a particular application. A familiar question in the literature of the information storage, selection and retrieval field relates to the relative efficiency of "linear" or "unit record" or "term-on-term" as versus "inverted" or "item-on-term" files, and combinations of these two approaches.[3.24a]

Some investigators who are concerned with problems of efficient file organization and file structuring from the points of view of effective

compartmentalization and efficient search strategies have never-the-less tended to neglect the problems and prospects of screening or sieving devices as an important contribution to search tactics.[3.42b]

An example of compartmentalization and screening techniques has been suggested in the case of fingerprint identification as follows: "If each fingerprint in a set is simply classified according to whether it conforms to a particular type of fingerprint pattern, e.g., 'whorl', the file can immediately be divided into 1.024 separate file sections representing the different possible combinations of the 10 fingers. More detailed analysis permits further refinement of the groups. With over a thousand file sections and the potential for easy subdivision within each section, the searching of even a multimillion-print file is not too forbidding." (Cuadra, 1966, p. 7).

On the hardware side, we are faced with severe problems of economic and practical feasibility in achieving large-scale, relationally associated data files to date. Small, very fast (e.g., tens of nanoseconds performance), memories of the associative or content-addressable type are beginning to appear in operational systems, primarily as "scratchpad" memories, which are defined as "small uniform access memories with access and cycle times matched to the clock of the logic" of the main processor. (Gluck, 1965, p. 662).

These scratchpad memories are typically used for such purposes as reducing time of access to instructions, microprogramming, buffering of instructions or of data that is transferable in small blocks (as in the "four-fetch" design of the Burroughs B 8500 system),[3.25] storage of intermediate processing results, table lookup operations, use as index registers,[3.25a] and, to a limited extent, content addressing.[3.26] Gunderson et al., of Honeywell (1966), discuss associative memory techniques as used for control functions in a multiprocessor system — more specifically, to provide dynamic control over processor assignments, to mechanize automatic page turning schemes, and to provide other functions relating to I/O executions and to parallel processing.[3.27]

Other than such scratchpad memory usage, several special-purpose and experimental associative memory developments may be of interest. One is Librascope's APP (*A*ssociative *P*arallel *P*rocessor), as described by Fuller and Bird (1965), intended for use in such tasks as pattern-property-extraction and pattern classification.[3.27a] Another example is the Pattern Articulation Unit and related parallel processing capabilities of the ILLIAC III computer.[3.27b]

In a 1966 survey, Hanlon reports that "memory cycle times have been reported as low as 50 nanoseconds" and that "although the majority of research to date has been with small memories (up to 1000 cells), projections are indicated in the 10^7–10^8 bit range. (p. 519)" Hobbs in one of a series of state-of-the-art reviews (1966) concurs in the opinion that advantages can be attained and disadvantages lessened by the use of a relatively small associative memory coupled to a large capacity random access store.

There may be other, as yet inadequately explored, alternatives, however. At Sylvania, for example, a reference-pattern-*plane* organization for the processing of unknown pattern inputs against many stored reference pattern property-criteria, has been experimentally realized in a combination of automatically processed plastic sheets affecting the behavior of a solenoid-transformer array for character recognition purposes. There are possibilities that the same addressed, transformer-sheet arrays, addressed in parallel searching mode, can be utilized as a practical associative memory of somewhat larger capacity, but slower speed, than those techniques available for internal[3.28] scratchpad auxiliaries.

In the light of present limitations of associative memory developments, Giuliano (1965) suggests this alternative:

"In my opinion . . . it would pay to look further into the area of large capacity, inexpensive permanent memory devices which would handle associative processing in a special-purpose manner". (p. 260) Wilkes (1965) suggests still another possibility: "So far the slave principle has been applied to very small super-speed memories associated with the control of a computer. There would, however, appear to be possibilities in the use of a normal sized core memory as a slave to a large core memory . . ." (p. 270)

Climenson comments: "A basic organization concept receiving little attention recently is King's photostore, where a large read-only disc memory is considered a logical extension of the stored program concept. The store is content-addressed, using a longest-match principle; the function found can be data or instructions, or both. The photostore is mentioned here because of the ultimate influence such devices could have on file organization. There may be renewed interest with the announcement of ITEK's version of the photostore: the Memory Centered Processor (MCP). ITEK's view is that the MCP is eminently suitable for sorting, compiling, file conversion, typesetting, and a host of other applications beyond the usual table lookup and file search." (Climenson, 1966, p. 112).

Present use of large-capacity associative memory techniques, however, has been limited not only by technological constraints but also by the even more difficult problems of deciding, in advance, what associations in a given body of data are most likely to be valuable for future processing service requests. Similarly, there are questions of how to represent efficiently the multiple cross-associations and interdependencies that may be identifiable. For example, in a 1966 study, Dugan et al. conclude that considerations involving the interrelationships between associative memories and general-purpose computers in various system configurations are the most important from the standpoint of system effectiveness.

Licklider has remarked that: "Associative, or content-addressable, memories are beginning to make their appearance in the computer technology. The first generation is, of course, too small and too expensive for applications of the kind we are interested in here, but the basic schema seems highly relevant." (1965, p. 64). He adds a *caveat,* however, as follows: "Only when the relative merits of various associative-memory organizations are understood in relation to various information-handling problems, we believe, should actual hardware memories be constructed." (p. 65).

4. Mass Storage Considerations

Turning next to very-large-capacity storage requirements, especially for permanent or archival information storage (such as record files, document collections, and libraries), we note the questions of digital as against facsimile storage media and techniques, the problems of document miniaturization or compacting of the document store, and the availability of so-called random access devices and systems. (The development of general purpose file management procedures and programs will be considered in a later report in this series).

4.1. Digital vs. Facsimile Storage

In the general area of efficient and economical storage, there is considerable continuing controversy with respect to digital as against facsimile storage, especially for documentary items to be maintained in files, with various levels of possible compromise also to be considered. There are, indeed, many considerations indicating that paper records, documents, and books will be always with us (the most obvious form of facsimile storage being that of storing the physical item itself), notwithstanding the possibilities for future development of new forms and media of information recording, publication, and dissemination.[4.1]

Furthermore, "the storage of the massive amounts of lexical material in libraries in digital (machine readable) form such as on the card catalogs, not to mention citations, abstracts, tables of contents or full text, requires memories of a size and organization not being met elsewhere in the data-processing industry." (King, 1965, p. 91). On the other hand, however, it has also been suggested that "it will not be long before it will be cheaper to store english text in the mass memory of a computer system than on paper in cabinet files." (Fano, 1967, p. 32). In general, there are both advantages and disadvantages in the choice of either digitalized or facsimile-reproducible storage for documentary items.

4.1.1. Facsimile Storage

Let us consider first the more conventional case of facsimile storage which may consist of the storage of one or more copies of the original record or document itself (e.g., carbon copies in correspondence files or bound volumes of printed pages and books on library shelves). Even in the most conventional library case, however, critical system considerations may arise in terms of the questions of whether, and when, to bind or to film.[4.2]

With respect to problems of document miniaturization for more compact facsimile-reproducible storage, the solutions of preference, to date, are those involving the use of microforms.[4.2a] The actual microform used may be roll microform; [4.3] cassettes, cartridges, or strips; [4.4] microfilm aperture cards,[4.5] or microfiche.[4.6]

Beyond the conventional microform having typical reduction ratios of 35–50 : 1 or less, a few systems involve 100 : 1 or greater reduction ratios, but typically only for very large, and very expensive, experimental systems.[4.7] Other factors are technological and involve, for example, the effects of size, contrast, media, resolution and other factors on the usefulness of microcopy, especially at high reduction ratios.[4.8]

Another approach to document miniaturization with facsimile image reproduction capabilities involves the use of video tape, but areas of continuing R & D concern are generally similar to those of the photographic-media microform techniques. In addition, it appears that video tape has the disadvantage of allowing only a limited number of replays (on the order of 100 or less).

Continuing system design problems in the handling and use of conventional microforms include questions of quality control of copy reproduction through several generations from a master [4.9] and of aging and preservation, (Fig. 3) especially of rare or irreplaceable items.[4.10] In general, system and clientele requirements continue to point to needs for higher quality and higher resolution, with greater accessibility and convenience of use, but at lower overall costs both to the system management requirements and to the individual user.

It may be noted in passing that an earlier claim for microform storage and retrieval advantages—namely, the convenience of using integral index techniques where content-indicating and other selection criteria codes are recorded physically adjacent to the item image(s) and where matching of query and item codes automatically triggers selection and reproduction of the indicated images [4.11]—is currently somewhat out of favor. A major reason for this is the developing sophistication of search strategy and multiple index manipulation techniques which may nevertheless be coupled with direct and automatic retrieval from microform files, but there are other reasons as well.[4.12]

An unusual example combining microform storage of document identifications, citations, and abstracts with coordinate indexing and Peek-a-boo type search and retrieval techniques is provided in the Microcite developments at the National Bureau of Standards.

FIGURE 3. *Aging blemishes on microfilm.*

FIGURE 4. *Microcite equipment.*

Peek-a-boo systems use term entry, aspect, or index term cards to index literature for later search. That is, coordinate locations on the card corresponding to document acquisition or identifier numbers are punched out as holes in just those index cards that represent the index terms applicable to that particular document. In searching, the cards corresponding to the terms used in a query or search prescription are superimposed and visually inspected for coincidences of punched-out holes. When such a coincidence exists, the document corresponding to the hole position meets the parameters of the search.

The output of such systems is usually a list of the document identification numbers, with a separate retrieval operation being required to select the corresponding documents from file, but the Microcite equipment (shown in Fig. 4) provides means for display and output copy of abstracts of documents

or of other data. These abstracts or data are stored as microimages on a film matrix. The location of each indicated hit is used as the reference point from which to position and project the image of each abstract for visual inspection by the searcher.[4.12a]

One major advantage of microform facsimile storage is the relative ease with which copies of information items of interest can be made available to the individual at his desk.[4.13] Another advantage beginning to be claimed for certain of the microform media is that of erasability and therefore of at least limited potentials for updating, correction, or re-use.[4.14] Among the media with this potential capability are some of the photosensitive dyes and thermoplastics.[4.15] An important feature of photochromic techniques is the capability provided for on-line inspection and opportunity for limited correction of errors.[4.16] (These and other advanced techniques for high density storage will be discussed in more detail in the third report in this series).

Questions of standardization and avoidance of duplication of effort are of concern to designers and users of new or improved microform storage systems. A significant advance toward systematic efforts in greater cooperation and compatibility was noted in the adoption, first by the U.S. Government,[4.17] and second by the United States American Standards Institute, of microfiche standards.[4.18]

It is to be noted that technological quality control standards are also of importance (e.g., the NBS Microcopy Resolution Test Chart, or line density standards),[4.19] that the National Microfilm Association continues to be interested in a variety of standards and standard specifications,[4.20] and that "two of the three most important objectives of standardization are already being realized, i.e., (1) recipients of microfiche from the four principal report-producing agencies are able to interfile microfiche, and (2) users are able to use the same equipment for viewing or otherwise processing such microfiche." (Schwelling, 1966, p. 36.[4.21]).

Avoidance of duplication of effort in the preparation and use of items stored in microform media involves current awareness of both existing standards and of availability of microcopies of various items in various forms.[4.21a] The *National Register of Microform Masters*, issued by the Library of Congress beginning in September 1965, provides a bibliographic record listing titles for which master microcopies exist, thus serving to minimize duplications of microcopying operations.[4.22] National and international guides to the availability of microform equipment provide additional sources of information.[4.23]

In terms of the conversion of hard copy to facsimile storage media, one particular problem area is that of the range of quality of source items for input to the microform store.[4.24] Another is the question of satisfactory reproduction of multilevel gray scale and of color.[4.24a] Handling problems are particularly severe in the case of microcopying from bound books.[4.25] However, as examples of recent developments, two models of portable cameras introduced by Data Reproduction Systems in 1965 allow for placement directly over the pages of an opened bound volume,[4.26] and competitive capabilities are claimed for a Houston Fearless microfiche camera-processor.[4.27] Page turners remain a problem. Questions remain as to the relative merits of positive vs. negative images from the point of view of the user.[4.28] For archival storage, however, studies at NBS have led to recommendations for storing positive copies together with careful periodic inspections of the filmed records (NBS Tech. Note 261).

4.1.2. Document Store Compacting by Digital Storage Techniques

As opposed to facsimile storage of documentary items and other extensive record collections, document compacting may also be achieved by digitalization of the information contained in the original item or record. The advantages of digital data storage are several fold. First is the advantage of direct accessibility. Accessibility to digitally stored data by an *on-line* combination of search, retrieval, and display techniques is an important new area of man-machine interaction, as noted in Section 2.2.1 of this report.

Significantly, direct accessibility to digitally stored data can be provided both for machines and for communication links without the need for manual or manual-mechanical handling. This capability leads to a second major advantage: that of manipulatability. Direct machine manipulation of digitally stored data can provide for reformatting of the information stored, for re-orderings of the store itself, for automatic transliterations, and for interconvertibility with respect to multiple modes of input-output and data transmission. Machine analyses of a wide variety of types and automatic report generation techniques are directly available.[4.29]

A third advantage might be termed "re-computability", which could provide for encoding and decoding of records and messages received (Schatz, 1967, p. 3), stored, retrieved, and re-transmitted. This capability is also available for direct application of error detection and error correction techniques, for machine reconstruction and display of digitized graphic images, and for image enhancement and information enhancement operations such as the cleaning-up of noise in a pattern recognition system. the automatic correlation of synonyms occurring in text, or the resolution of homographic ambiguity by machine examination of contextual clues. (These topics are discussed in other reports in this series).

Automatic machine control of the redundancy of digitally stored information is also in prospect, especially with respect to duplicate checking, validation, and data correlation and consolidation. Such operations may be directed first toward the reduction of duplication as between items stored and with respect to the information contents of various

items. Secondly, such consolidation or correlation may be designed to provide for the validation and verification of information contained in several messages or items. A third purpose of data consolidation is to provide, through aggregation or partial aggregation, protection of the identity of individual reporting units from unauthorized disclosure.[4.29a]

4.1.3. Combined Facsimile-Digital Storage

Since there are both advantages and disadvantages to either facsimile or digital storage, some information processing system design considerations involve various possible combinations of storage media and retrieval techniques. The classic precedent is the Bush Rapid Selector, where the facsimile image on microfilm is directly associated with a digitally recorded selection-criteria encoding and where machine matches of selection-criteria codes in a query with those recorded for stored items automatically trigger the reproduction of the facsimile images of the selected items.[4.30]

In relatively small-scale and inexpensive systems, a wide variety of digital codes (in edge-notching,[4.31] color coding,[4.31a] and so forth) are used for "homing" on subsets of items recorded for storage and retrieval in facsimile form or for direct selection of the individual item itself. Similar techniques are employed in some of the more recent large-scale microform retrieval systems, such as Magnavue (to be discussed below).

Then it is to be noted that ". . . the photographic emulsion can also be used to store digital information. If this is done, a reel of film acquires all of the functional virtues of digital tape while avoiding its information storage limitations. Optical means, such as flying spot scanner techniques, can be used to read the digital information at rates which compare favorably with the electronic reading of digital tape." (Condon, 1963, p. 137). An advanced technique involves laser recording of digitally encoded identification, content-indication, and other selection information on high resolution microforms.[4.31b]

Another approach to multi-bit storage is that of Lamberts and Higgins of Eastman Kodak who use the recording of diffraction grating patterns on high-resolution film involving composites of the grating patterns of seven spatial-frequency components of a character. These investigators point out that this approach is closely similar to that of holography: "In fact, it turns out that a composite grating is essentially a Fraunhofer-type hologram of a series of bright points." (Lamberts and Higgins, 1966, p. 730).[4.31c]

In general, however, advanced techniques for truly high density storage, promising such possibilities as 13 million bits in a photochromic film memory plane two inches square (Reich and Dorion, 1965), or Honeywell developments indicating potential storage of "two million bits . . . on a surface the size of a dime" (Commun. ACM **11**, 66, Jan. 1968) will be discussed in the next report in this series, concerned with overall information processing system design requirements.

4.2. Examples of Relatively Direct Access File Storage and Retrieval Systems

The terminology "random access" as applied to mass data and file storage and retrieval techniques is generally misleading. What is usually meant is that the access time to items or records wherever located in the storage medium or device is approximately the same for all items and "very much shorter than the initial access time of serial memories". (Licklider, 1965, p. 16). Further, as Poland emphasizes, "only with direct-access, mass-storage equipment can randomly related references to data files be made in an economical and expeditious manner." (Poland, 1965, p. 249).

4.2.1. Retrieval and Reproduction of Microforms

A wide range of equipment is available for the manual, semiautomatic, or automatic (e.g., computer-manipulated[4.32]) retrieval, re-enlargement, display, and copy reproduction of conventional microforms such as roll microfilm, microfilm strips and microfilm aperture cards. In addition, systems such as LODESTAR[4.33] and other current developments involve the use of cartridges, cassettes, and magazines to improve access. Relatively recent examples include the VSMF (Visual Search Microfilm Files) System of Information Handling Services, Inc.,[4.34] 3M's Filmac 400,[4.35] and Recordak's Miracode Microstrip Systems.[4.36] Other relatively small-scale systems include Remstar,[4.37] the Randomatic Data System's equipment for keyboarded indexing and retrieval of edge-notched paper, plastic or film cards, the Randtriever System,[4.38] and Mosler Safe Company's Selectriever.[4.39]

Examples of commercially available retrieval devices for microfiche in particular include the Houston Fearless Film CARD (Compact Automatic Retrieval-Display) desktop reader, which provides 4-second (or less) random access to approximately 70,000 pages in any one of a number of interchangeable magazines;[4.40] the Itek 18.24 Reader-Printer which handles aperture cards, roll film, microfilm jackets, and microfiches up to 5″ x 8″ with selective masking, variable size print and high-contrast opaque or translucent copies (Systems **6**, No. 6, 39 (1965).), DuKane's desktop viewer for microfiche in various sizes also up to 5″ x 8″ at 15× magnification; Recordak FILMCARD readers; a desktop reader from Data Reproduction Systems; the Microcard EL–4 Automatic Enlarger-Printer, and others.

Advanced or large-scale systems are also beginning to come into operation, at least on an experimental basis. Among these are the DARE (Documentation Automated Retrieval Equipment), the Ampex Videofile system, the high-resolution Micro-

Vue, and SDC's Satire system. Thus, at the U.S. Army Missile Command, the DARE system utilizes Magnavox Magnavue equipment, under computer control, for a large file of engineering drawings recorded on film chips.[4.41] Also under U.S. Army sponsorship, at Huntsville, developments include combined usage of Alden/Miracode techniques [4.42] with the semi-automatic generation of Miracode film.

The Videofilm techniques involve the storage, retrieval, and reproduction of microforms in the special sense of recordings on video tape. The initial videofile approaches to these techniques at Radio Corporation of America have apparently been at least temporarily abandoned, because of probable high costs, in favor of RACE, techniques involving the use of relatively large-sized magnetic cards with apertures for optical images.[4.43] However, Ampex has embarked on a program of development and marketing of a somewhat more modest Videofile system, including remote query capabilities.[4.44]

The Micro-Vue system developed by the Republic Aviation Division of Fairchild Hiller Corp., involves reduction ratios up to 260:1, so that as many as 10,000 page images can be recorded on a single 4″ x 5″ microfiche. These "ultrafiches" can be loaded into 20-chip holders with random access to any one of the 200,000 stored images in, at most, 30 seconds. (Systems **8**, No. 1, 6 (Jan. 1967).)[4.45] Photochromic materials (as discussed elsewhere in this series of reports) also promise high reduction ratios. For example, developments at NCR include the recording of up to 3,000 microimages on a single microform convenient for multiple distribution, i.e., as a microform publication medium.[4.45a]

Other experimental developments in microform storage include work at Aeroflex Laboratories,[4.46] and further improvements in both photoplastic recording and the Photocharge recording process at G.E.[4.47] Then there are the successive Walnut, Cypress, and 1350 systems developed by IBM, although there is some doubt that any of these will continue to be available for graphic storage.[4.48] The IBM 1360, a film chip system discontinued after the delivery of two models to the Atomic Energy Commission, was described by Kuehler and Kerby, 1966.[4.48a] However, the high density photographic storage technique has considerable promise for very large capacity digital data storage, to be considered next.

4.2.2. Digital Data Storage Techniques

The media and methods available for digital data storage include high-resolution photographic materials, magnetic media, advanced developments using laser recording techniques, and other special materials and techniques. For high density digital data storage, magnetic technique developments include larger and higher-speed bulk core storage, especially with new types of tiny cores;[4.49] discs and disc pack units with capacities ranging to billions of bits of data and access times of 100 or less milliseconds;[4.50] drums,[4.51] and magnetic cards and data cells.[4.52]

Pyke summarizes the current situation with respect to magnetic media as follows: "A large effort is now being expended on the development of mass storage devices. Larger and faster bulk cores are being designed. Drums operating with parallel transfer and with logic for queuing access requests, thus optimizing drum operation, are forthcoming. Disk units with an individual head per track are becoming available and devices such as data cells promise many billions of bits of storage at a reasonable cost." (Pyke, 1967, p. 162).

From an applications standpoint, Bonn emphasizes that "the currently used devices are drums, disk files, magnetic card devices, and tape loop units. These machines all store large amounts of data, from 6.5 million to 4.8 billion bits, on-line in one device at any one time. Any of the stored information can be retrieved without reading the intervening data between two desired records. Any record can be written or modified without operation on any other record. Records in mass storage devices can be updated in place." (Bonn, 1966, p. 1861).

In the area of advanced developments for digital data storage involving electron or laser beam recording onto photographic media, semiconductor films, or thin metallic foils, examples include the Dove Data Storage and Retrieval System,[4.53] IBM's "trillion-bit" memory recently delivered to the Atomic Energy Commission,[4.54] and the UNICON technique developed by the Precision Instrument Company.[4.55] In addition, Kump and Chang (1966) provide a discussion of a thermostrictive recording technique for Permalloy films, achieved by the application of local stresses induced by laser or electron beam, which is claimed to promise future mass memories with storage efficiencies of a million bits per square inch.

Then we note, on the one hand, that portable digital data storage modules are under development that will enable interchangability on standard input/output equipment, much as magnetic tapes reels are now handled,[4.56] and that, on the other hand, "breakthroughs we seek in mass memory may come from the molecular engineers, who can develop improved materials with which we can fully exploit the inertialess properties of light and electron beams to write and read data bits closely approaching molecular size." (Hoagland, 1965, p. 57).

5. Output and Post-Processing Requirements

Referring back to Figure 1, we see that system outputs may occur directly (Box 5) or, in Box 14, as the result of file searches or as subjected to a variety of post-processing operations (Box 13). In Figure 5, we show some of the areas of continuing R & D concern with respect to the output and post-processing functions. It has been claimed that, in general, too little attention has been given to

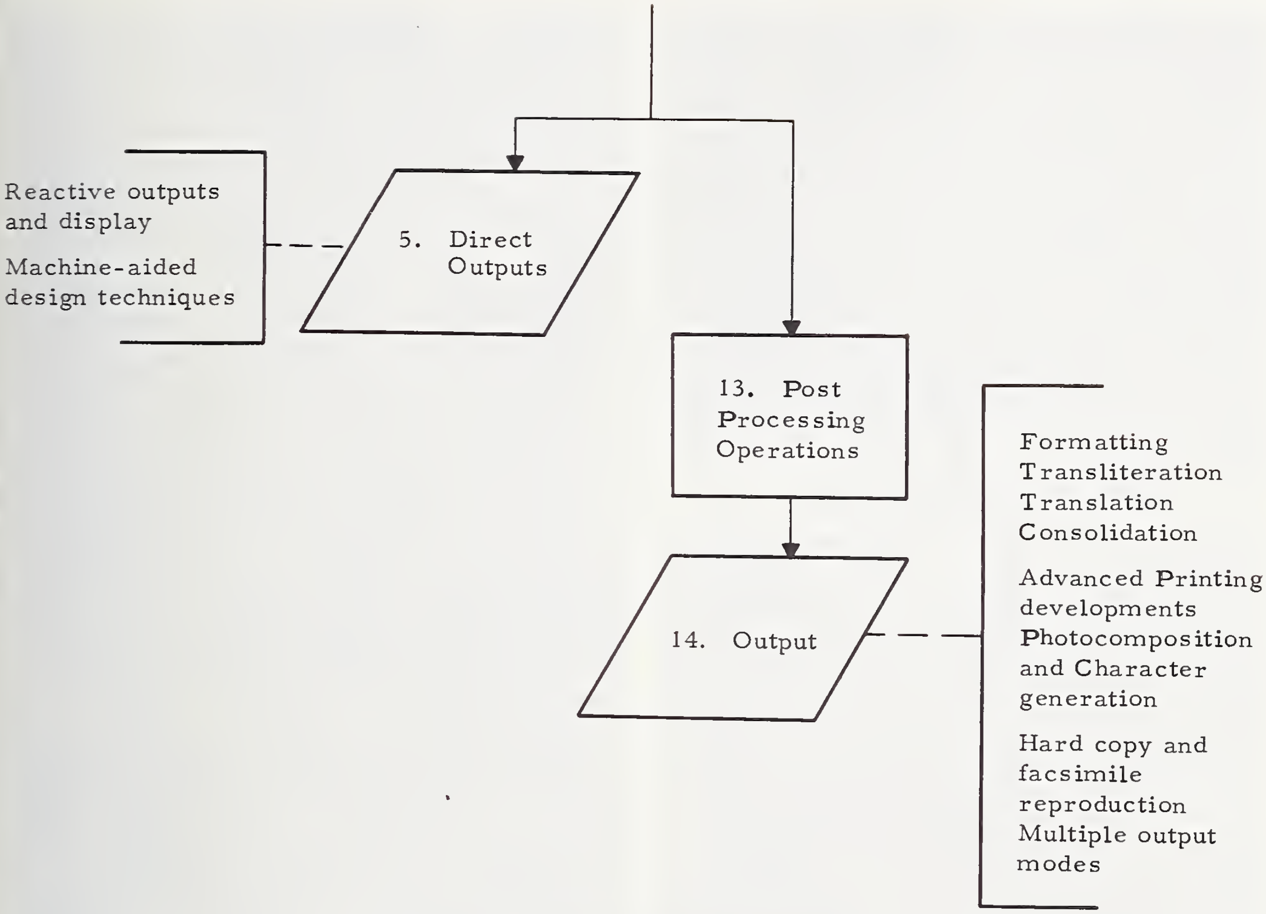

FIGURE 5. *Output and post-processing functions.*

output requirements in information processing system design.[5.1a] Further, it is noted that "the completeness, accuracy, and accessibility of system outputs are each individually dependent upon system design and can be improved through improvement in system design." (Davis, 1967, p. 8).

First, advanced developments of direct output modes with interactive man-machine response may be considered, especially with respect to graphic displays, to applications such as computer-assisted instruction and machine-aided design, and to prospects of color, three-dimensional and motion picture outputs.

5.1. Direct Output and Display Applications

Direct output and display requirements for the foreseeable future encompass a wide variety of user-oriented capabilities, some of which are commercially available on at least a limited basis today and some of which will require further research, development, and production engineering. Application areas of current R & D concern include those of computer-aided instruction, machine-aided design, and machine-aided problem-solving systems.

For each of these purposes, if the computer outputs are direct, they should in the first place be *responsive* to the processing service requests, they should be presentable in terms of legibility and convenience, and they should be produced with capabilities for on-line modification within a reasonable time scale. Bauer presents a concise statement of a minimum of four capabilities that a responsive display system should have in order to provide assistance to the human partner in many man-machine interactive situations. They are:

"1. Correct an input
2. Accept a query or the specification of an operation, then perform the required or desired operation which should provide the proper information to the user necessary to accomplish the next step.
3. Accept and appropriately handle information to enable the computer to interpret correctly future information which it may receive from the user, or
4. Direct, on a step by step basis, a procedure for information input and output." (Bauer, 1965, pp. 17–18).

In addition, console capabilities for "soft" (or transient) displays should provide flexible and convenient editing and control facilities including insertions, deletions, corrections, rearrangements, scale-changing, size and rotational transformations, automatic multiple copying, and the like. Still other uses of on-line reactive displays are for purposes of text editing, sorting, and printing as for example in programs under development at Bell Laboratories (Mathews and Miller, 1965) and at the University of Pittsburgh. (Roudabush et al., 1965).[5.1b] When such techniques are applied to a complete publication cycle, by feeding the corrected tape products either off-line to automatic composing machines or on-line to a computer typesetting program, the loop is closed from original data to finished output product.[5.1c]

5.1.1. Graphic Output and Display

At least as early as 1953, a CRT display system was available on the Illiac.[5.2] Similarly, "Whirlwind (at MIT) had a cathode ray tube and light pen in the early 1950's. A prototype of the APT system (computer controlled machine tool) was programmed on Whirlwind in 1955." (Wigington, 1966, p. 86). Reactive display for purposes of air traffic control applications was investigated in the early 1950's at the National Bureau of Standards. A combination of the DYSEAC computer, special display equipment, control devices including a joystick serving a light pen funtion, and a radar link to the Washington National Airport provided the basis for on-line, real-time experimentation. With actual radar data being displayed on one scope, the operator was able to indicate targets of special interest which should be marked or brightened for him, and a second scope displayed the results of computer predictions of expected positions of target aircraft within specified time intervals. The same equipment could also be used for problem-solving simulations, such as war gaming.[5.3]

By 1962, an advertisement asked, with appropriate illustrations, "Would you believe a Calcomp plotter and any computer can draw pictures like these in seconds? . . . A perspective sketch of your new plant. . . . Statistical trend charts . . . molecular structure diagrams . . . apparel patterns, graded for sizes . . . and even the Mona Lisa". (Commun. ACM **10**, A9 (1962).)

The development of full-scale graphical input-output communication and processing systems, with particular emphasis on man-machine problem-solving is of course represented first by M.I.T.'s Sketchpad. This was publicly introduced at the 1963 Spring Joint Computer Conference where Coons outlined the requirements for a computer-aided design system;[5.4] Ross and Rodriguez discussed the theoretical foundations of such systems, with emphasis upon appropriate languages and data structures; Stotz described the man-machine console facilities, specifically including the display requirements;[5.5] Sutherland outlined the Sketchpad graphical communication system itself,[5.6] and an extension to three-dimensional drawing applications, Sketchpad III, was outlined by Johnson. The latter investigator remarked: "General three-dimensional graphical communication, which deals with arbitrary surfaces and space curve intersections, presents many difficult problems; the beginning has been modest and much work remains before the complete graphical communication problem is solved." (1963, p. 347).

Organizations neighboring M.I.T. have also been engaged in the development and utilization of graphic input-output equipment for man-machine reactive display in problem-solving applications, notably, Bolt, Beranek and Newman[5.7] and the MITRE Corporation.[5.8] More recently, it is to be noted that: "Computer-made maps presenting physical, economic and social data in easily understood graphic form will be produced, along with similar diagrams, charts and graphs, in a new Laboratory for Computer Graphics at Harvard's Graduate School of Design." (Commun. ACM **9**, 310 (1966).) Chasen and Seitz (1967) consider not only the early sketchpad developments, but also those of Lockheed-Georgia, IBM, Control Data Corporation, and General Motors.[5.8a]

Other experimental on-line data analysis and display systems include APEX at M.I.T.'s Lincoln Laboratory (Forgie, 1965), and the similar capabilities of the SDC Variable Display system (Schwartz et al., 1965) and its Graphic Tablet Display.[5.8b] A West German example involves a Telefunken combination of a display console and its TR–4 computer for air traffic control applications. (Stevens, 1968, p. 9) In this system, a manually controlled moving ball permits the translation of displayed images and the multidirectional scanning of different areas shown on the display scope. At the National Bureau of Standards, developments in graphic input-output, such as ACCESS and MAGIC, are designed for differing types of requirements in U.S. Government organizations.[5.9]

Then there is the time-sharing facility for experiments in man-machine interaction at the Computer Center of the University of California, Berkeley, which is described by Lichtenberger and Pirtle (1965). In effect, the user has available to him a Scientific Data Systems (SDS) 930 computer with 16,000 words of fast memory, modified to exclude his direct access to input-output instructions (which, instead, are carried out for him by the system executive) and by additional software-interpreted instructions. Remote access facilities include teletypes, CRT display keyboards and a small DPP–5 processor equipped both with a CRT display unit and a RAND Tablet.

In addition to the Digital Equipment Corporation's graphic input/output equipment used in many of the pioneering and continuing responsive-output applications,[5.10] a relatively wide variety of graphic output and display devices is also offered by various other suppliers. Examples include, but are obviously

not limited to Bell Laboratories' "Glance";[5.11] Benson-Lehner developments;[5.12] Bunker-Ramo equipment;[5.13] Datatronics Engineers, Inc.;[5.14] Gerber Scientific Instrument Co.;[5.15] Information Displays, Inc.;[5.16] Informatics' DOCUS (*D*isplay *O*riented *C*ompiler *U*sage *S*ystem) for the Rome Air Development Center;[5.17] ITT Federal Laboratories;[5.18] Minnesota Mining and Manufacturing Co.;[5.19] Philco;[5.20] Sanders Associates;[5.21] Stromberg-Carlson (especially the SC-1100 Display Inquiry Station and the SC-1200 Digital to Video Display for computer applications involving multiple access to data at remote locations), and the Tasker Instruments Corp.[5.22] In general, as of 1967, the majority of computer manufacturers also offer graphic input-output capabilities via peripheral equipment that can be connected on-line to the central processing facilities. Obvious examples include UNIVAC, IBM, Honeywell, Control Data, and others.[5.23]

Some of the new applications of user-controlled graphic input and output devices include the on-line alteration of a PERT (*P*rogram *E*valuation and *R*eview *T*echnique) network display to determine the effects of setting different target dates;[5.24] Control Data Corporation's computer-directed construction drawing system involving long distance telephone lines for transfer of problem and solution data (Business Automation **12**, No. 7, 55, July, 1965), and the Comex (*C*ommand *E*xecutor) system which allows "several simulated commanders to use a subset of English to control the flight of simulated objects on the system's display console. Heading, course, range, altitude, velocity, and destination can each be controlled by English statements typed into Comex on-line." (Schwartz et al., 1965, p. 29).

Walter (1967) claims that "immediate application of graphic data processing to solve a variety of problems is both physically possible and economically desirable. Graphic data processing can be effectively applied in mathematics, engineering, banking, education, communications, medicine, management information systems, programming, and many other fields." (Walter, 1967, p. 107).

Similarly, Prince reports that "a number of industrial, government, and university laboratories are exploring various applications of graphical computer-aided design. Applications receiving primary attention include the preparation of digital tapes for numerically controlled cutting tools, trajectory studies, structural analysis, aircraft and automotive shape design, shipbuilding, flight test data reduction, circuit analysis, and printed circuit board layout. Most of these must be considered as experimental programs; only a very few are in a production status." (Prince, 1966, p. 1701).

Yet, there are many areas of continuing R & D concern with respect to character sets and remote terminal design (to be considered in the next report in this series), hardware limitations, and human engineering considerations.[5.24a] For example, Walter of Honeywell, Inc. (1967) asks: "Can mathematical techniques be used to improve the accuracy of a computer graphic output device despite its hardware limitations? This developmental research problem involves discriminatory analysis, differential equations, and simulation." (p. 107).

Then we note that: "Davis has stated that because of the universality of pictures the 'improvement of display techniques has gone hand-in-hand with man's progress in every field of human endeavor.' Unfortunately, the road to good displays has not been smooth. In her paper, which surveys the history of displays, she points out how disorganized, spasmodic and even serendipitous has been the improvement in displays." (Davis, 1966, p. 236).

Mills reports that "a very thorough treatment of computer-driven displays and their use in man-machine interaction is given by Van Dam. This paper—really a mongraph—includes a brief history, a thorough treatment of display technology at a very satisfying level of technical thoroughness and depth, and a survey of some of the applications of man-machine interactive systems involving display terminal devices. Sixty bibliographic citations are included. This is one of the few papers to recognize that imaging techniques other than those based on cathode ray tubes may have an application in graphic terminal devices; some half-dozen non-CRT techniques are mentioned. The communication problems raised by moving the display terminal to a remote location are not considered. Sutherland treats the state of the art in computer graphics and indicates some further requirements. The paper is not really limited to the issues of computer graphics but considers them within the context of man-machine coupling." (Mills, 1967, p. 231).

5.1.2. Machine-Aided Design

One of the most challenging areas of information processing system output is unquestionably that of reactive display and response between man, machine, and data banks in machine-aided design applications.[5.25] Graphic input-output capabilities, together with man-machine-interactive on-line modifications, are essential to the machine-aided design procedures. A pioneering type of application to problems of hospital and architectural design, discussed by Licklider and Clark (1962) several years before the General Motor's DAC (Design Augmented by Computers) system's claim for a "first", (as of Fall, 1964, see Hargraves et al.) has had continuing development and expansion by Bolt, Beranek and Newman personnel. (Fig. 6) The DAC system, on the other hand, includes rapid-response microfilming and microfilm re-display, also evidenced in such developments as an IBM graphic data processing system[5.26] and the D-200 equipment offered by Strand Division of Datatronics Engineers, Inc.[5.27]

There are a number of isolated, but intriguing, examples of machine-aided design applications ranging from the design of ships[5.28] to the CADET (*C*omputer-*A*ided *D*esign *E*xperiment *T*ranslator) system described by Lang et al. (1965), which has

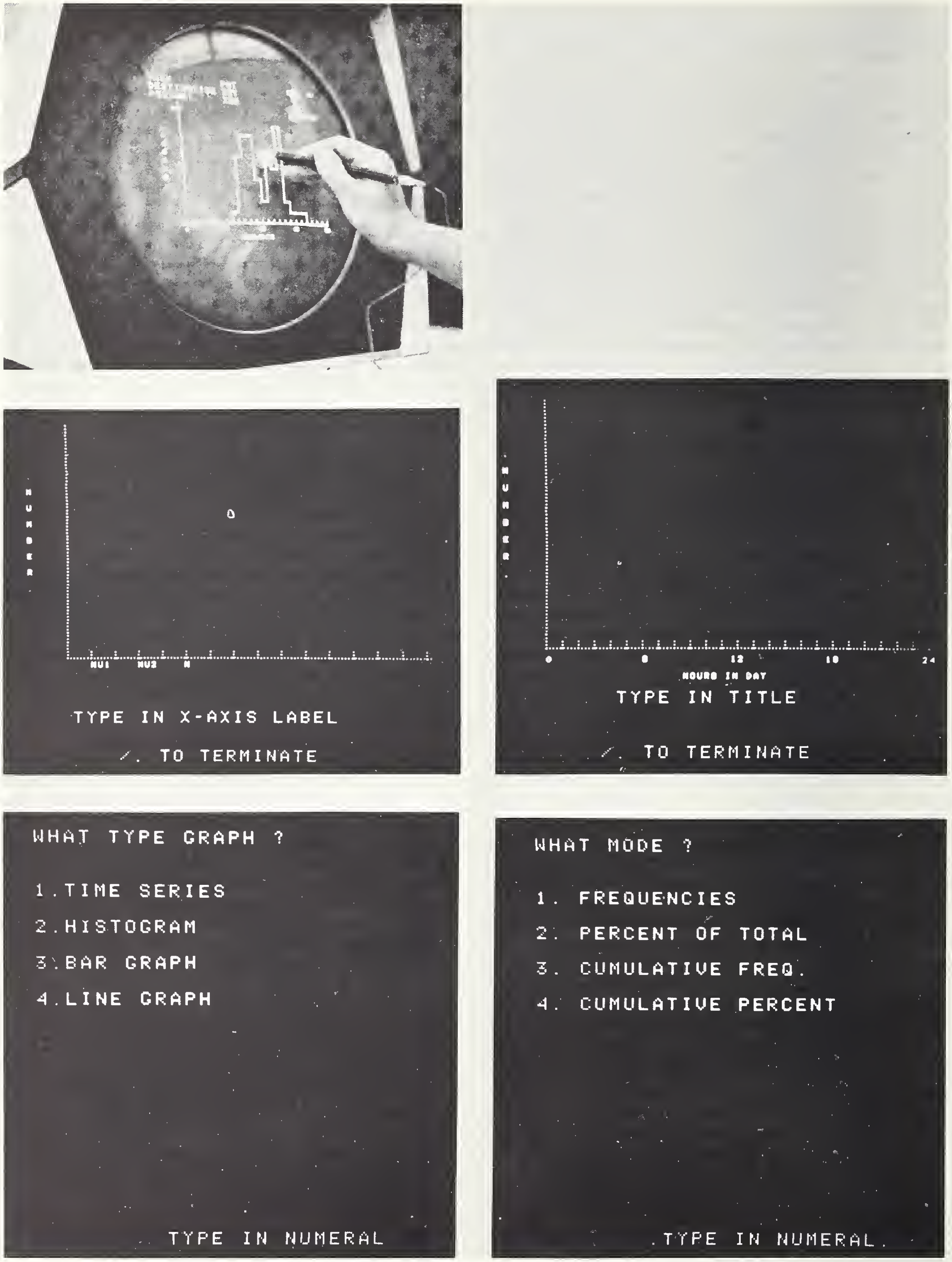

FIGURE 6. *The "co-planner" outputs.*

been designed for such processing tasks as three-dimensional shape description and the development of non-linear electronic circuit designs.[5.29] Other areas of applicability include aerospace research,[5.30] design of aircraft and automobiles,[5.31] other architectural developments[5.31a] and civil engineering and highway design, including the design of a super-highway interchange in a brief ten minutes by an engineer using a remote communication link to MIT's MULTICS (*Mult*iplexed *I*nformation and *C*omputing *S*ervice) system.[5.31b] Machine-aided design has also been extended to the fields of the arts and crafts, notably in the area of textile design.[5.32]

In addition, at the University of California at Santa Barbara there is the Culler-Fried system for "computer displaying and of transforming mathematical functions in their pathologic intervals" (Cheydleur, 1965, p. 175) and Engelman states that "W. A. Martin . . . [is] working on input from scopes achieved by signifying with a light pen an interesting subexpression of a previously 'printed' expression, as well as anticipating using the scopes for handwritten input".[5.32a] Ruyle et al., provide a 1967 status report on systems developed for on-line mathematical problem-solving including AMTRAN,[5.32b] Culler-Fried,[5.32c] the Lincoln Reckoner,[5.32d] MAP,[5.32e] and MATHLAB.[5.32f] The work at Hudson Laboratories, Columbia University, is also to be noted.[5.32g]

A general survey of computer applications to design of computers is provided by Breuer (1966), who cites some 287 references. Also in the area of "shoes for the shoemaker's children", reactive display and input devices are already being applied to machine-aided programming, flowcharting and system design operations.[5.33] It is noted also that Anderson has used an IBM 1620 together with a Calcomp digital incremental plotter to produce annotated flow charts on line[5.34] and commercial packages for this purpose, such as AUTOFLOW[5.35] or Autodigrammer[5.35a] are now available. Then it is claimed that Bell Lab's FLOWTRACE can produce "flowcharts written in 'almost any' programming language." (Sherman, 1966, p. 845). Other examples include the IBM System/360 Flowchart,[5.35b] and the Usercode Documentor and Flowlister,[5.35c] while Abrams (1968) discusses a number of systems.[5.35d]

Developments have been reported in machine-aided circuit analysis, schematic circuit design, and system block diagram construction.[5.36] LeVier (1965) describes a program for the circuit design of a transistorized flip flop, Wall and Falk (1966) describe an IBM program for electronic circuit analysis, and Shalla (1966) reports a mapping from block diagrams of electronic digital circuits into list structures and the use of a list processing program for the Control Data 3600 to carry out circuit analysis. In particular, some examples of actual hardware for an Argonne National Laboratory computer were tested. Then there are the CIRCAL (CIRCuit AnaLysis) programs available on the Project MAC facilities (Dertouzos, 1967). Ninke (1965, p. 846) describes an IBM 7094 application in which "a system block diagram composed at the console can be used as input to a special compiler, the compiled program can be run and the results viewed at the console."[5.37] However, "we are only just beginning to explore systems where the computer asks questions of the programmer to resolve ambiguities in what it is told." (Sutherland, 1965, p. 11).

Hardware, software, and systems planning considerations involving human engineering considerations and human behavioral factors, come especially to the fore in experimental applications, such as the following:

(1) "A few users have experienced the delight of sketching and printing to the computer and having it 'clean up the input' and then generate labeled graphs and drawings in response . . ." (Licklider, 1965, p. 182).

(2) "In the study of computer-aided design . . . graphical communication should be a two-way process, for the designer wishes to enter drawings of objects into the computer for analysis and likewise he wishes to see computer-generated or modified drawings." (Lang et al., 1965, p. 1).

(3) "The engineer must do more than use the computer. He must actively participate in the computer solution. To do this he needs a *language* to *communicate* with the computer, physical *accessibility* to the computer, and a mechanism for obtaining *engineering-oriented results* from the computer." (Roos, 1965, p. 423).

(4) "We are therefore witnessing the first inroad of machine assistance into the human decision areas of printing design. It is ironical that only a few years after printers and designers threw up their hands in horror at the idea of machines robbing them of their traditional role in printing practice, we should see them being actively taken back into a partnership with the machine in which their specialised talents are being very much enhanced by machine assistance." (Duncan, 1967, pp. x–xi).

(5) "An engineer may, for example, substitute different values of components in a circuit and observe the effect in the form of a picture of the output wave that would be produced by the circuit in question under any combination of conditions. He may also record the various changes on microfilm and observe them later via a projection device at the same console. He may magnify sections of a diagram for detailed study and manipulation, retaining the ability to return the original picture to the screen at any time." (Silveira, 1965, p. 37).

Next, therefore, we may ask how conveniently the potential system client may thus interact with the machine.

What processing operations are automatically available to the user as he watches and wishes to modify the data pertinent to his problem displayed for him? In systems such as Sketchpad he may apply scaling and rotational transformations of the image displayed,[5.38] in CALCULAID[5.38a] or MAP* he may call directly for regression or Fourier transform operations,[5.39] and, in general, he needs to be able to request as directly as possible the performance of a specified operation, a display of the consequences of his proposed modifications, and the re-input of specifications of the next processing operations to be performed which he has determined on the basis of the previous results.[5.40]

Finally we note that utilization of direct outputs, whether by man or machine or by both, involves also the possibility of *reactive control* and of interruptibility and re-direction of source data automation, intermediate processing, intrapolation and extrapolation of results. Feedback of various types is an important concern.[5.40a] The problems of man-machine interactive situations at the levels of terminal design, user-oriented languages, human engineering, and behavioral or attitudinal factors will thus require continuing R & D attention.[5.40b]

5.1.3. Computer-Assisted Instruction and Problem-Solving

The problems of computer-aided instruction present, at least in the general literature surveyed, somewhat less in the way of continuing R & D implications than is the case for machine-aided design or machine-aided inference. Nevertheless, the field of CAI represents an important area of development and application.[5.41] In its computer directory issue of June 1968, Computers and Automation provides a roster of 40 CAI centers and laboratories. Silvern and Silvern emphasize that: "CAI, computer-assisted instruction, developed from dissatisfaction with simple text formats and teaching machines which did little more than automatically turn pages for the student. Early investigators saw, in the digital computer's capability, the seeds of two-way, learner-machine *dialogues* which would lead a student along a path which more primitive methods failed to travel." (Silvern and Silvern, 1966, p. 57).[5.41a]

Examples of CAI systems include the PLATO (*P*rogrammed *L*ogic for *A*utomatic *T*eaching *O*perations) system developed by the Coordinated Science Laboratory of the University of Illinois,[5.42] the CLASS (*C*omputer-Based *L*aboratory for *A*utomated *S*chool *S*ystems) facilities developed at System Development Corporation,[5.43] PLANIT (*P*rogramming *Lan*guage for *I*nteraction and *T*eaching)[5.43a] and the Socratic System as described by Muerzeig in 1965. IBM has developed the 1500 Instructional System[5.44] and Engvold and Hughes of IBM describe (1967) adaptation of the 7044 Graphic System to a teaching system which can be interleaved with programming problems to be handled in a variety of languages at the display console.

Still other examples include the simulation by students of experiments in chemical analysis[5.45] and a Bolt, Beranek and Newman development where the computer deliberately introduces ambiguities into an interactive system designed to teach medical diagnosis. (Science, Oct. 29, 1965, pp. 572–576). Byproduct advantages of CAI techniques include automatic performance measurements of student progress.[5.46] Then it is pointed out that "remote terminals used for CAI can also be used to provide instructions for leading the student to appropriate supplementary material stored on microform." (Burchinal, 1967, p. 4).

Crowell and Traedge, 1967, provide a review and bibliography of developments in computer-assisted instruction. In addition, they suggest areas for continuing R & D efforts. They conclude, in particular, that "before assigning system functions to either man or computer . . . much research is needed in analyzing the decision-making process. When such information is added to our present store of knowledge concerning man-machine factors, greater efficiency in CAI systems will be realized." (p. 423).

Other commentators similarly suggest that a great deal of work remains to be done (Adams, 1966), that, "without discredit to the good work now under way, . . . the total level of the effort is unacceptably small" (Mills, 1967, p. 237), and that "although man-machine interaction may eventually revolutionize problem-solving, even the leaders in the field are just taking their first hesitant steps into the deep unknown of joint human-computer problem-solving techniques." (Davis, 1966, p. 243).

5.2. Multiple Output Modes

For information processing systems generally, output, like input, should be available in a variety of modalities—visual, as in printing and in graphic displays; voice and other audio signal outputs; control signals, mechanical displacements of pointers and plotting devices, and the like. Output results may be presented immediately to the operator or user, recorded photographically, or fed to various types of communication links, including telephone, coaxial cable, and facsimile transmission lines. Before discussing the more conventional forms of output, such as the use of printers and plotters, and hard copy requirements generally, let us consider in this section audio outputs; three-dimensional, color, and motion picture outputs, and some examples of systems using various combinations of output techniques.

*See note 5.32a.

5.2.1. Audio Outputs, Speech Synthesis and Speech Compression

Unlike the problem of voice inputs, audio output devices are already available, at least for somewhat limited sets of response messages.[5.46a] Examples are the IBM 7770 device with a fixed, pre-recorded vocabulary of up to 128 response words and the IBM 7772 audio unit[5.47] which by vocoder techniques[5.48] can generate several thousand distinct words (in one or more languages)[5.48a] as auditory outputs, the Cognitronic's Speechmaker[5.49] an RCA unit designed for use with Spectra systems,[5.50] developments by Burroughs,[5.50a] equipment developed by Westinghouse Electric for computer-student communication at Stanford University,[5.51] and an early model developed at the Rome Air Development Center.[5.51a]

Application areas of interest range from direct assistance not only to students[5.52] but also to practicing physicians,[5.53] to the systems developed for the New York Stock Exchange (Proctor, 1966), for banking operations,[5.54] and for engineering design information recall at North American Aviation.[5.55] Gentle suggests that "voice answerback systems will increase in number as more computer manufacturers build the capability into their equipment. The increasing availability of tone dialing telephones will also hasten the use of these systems because the use of the regular telephone for inqüiry and voice answerback permits almost anyone in any location to use the service." (Gentle, 1965, p. 87).[5.55a]

The closely related areas of speech synthesis and vocoding techniques are also important with respect to improved communication and processing systems of the future because of the potentialities offered for significant compression of speech signals to be transmitted via various communication links. R & D objectives at the Bell Telephone Laboratories and elsewhere are to reduce the typical bandwidth of 78,000–56,000 bits per second for direct digital encoding of analog speech signals to 2,400, 1,200 or even fewer bps, more closely approximating the probable information content of digital speech signals (i.e., about 50 bits per second).[5.55b]

Examples of current and continuing R & D efforts in the areas of speech synthesis and speech compression are to be found at the Royal Institute of Technology in Sweden,[5.56] at the University of Manchester, England,[5.56a] at M.I.T.,[5.57] and at the Haskins Laboratories.[5.58] In all of these cases, and in other organizations as well, there is considerable R & D interest in the design of improved aids to the handicapped. For example, at R.I.T., Risberg has demonstrated speech analysis hardware with rapid response displays of both spectrum and frequencies so that the deaf child can see the results of his attempts at speech, and can therefore make instantaneous adjustments. At M.I.T., a recent example involves developments in reading aids for the blind.[5.59] Similarly, Lee reports of a computer speech generation technique designed for transliteration of connected speech as related to reading machines for the blind.[5.59a1]

Problems of formant amplitudes in synthesis of natural-sounding speech have been studied by Fant and his associates,[5.59a2] while Woodward has been concerned with formant persistence and with intonation.[5.59a3] Allen (1968) points to a number of R & D problems remaining in the area of the synthesis and output of connected speech. These include problems of stress, punctuation and phrase boundaries, intonation, and the like.[5.59b] This investigator is exploring a syntactic bracketing approach to the solution of some of these problems.[5.59c]

Becker and Poza (1968) are investigating natural rather than synthetic speech for computer-controlled output and are concerned with the significant reduction of storage requirements for natural speech waveforms. More particularly, they are concerned with dyads (that is, the last half of one sound and the first half of a following sound). These dyads may be manually inspected and marked out from displays of typical speech segments and subsequently recombined to provide at least some of the natural transitions of speech for large vocabularies, but requiring only a relatively few number of dyads to be stored (e.g., 800 for monotonic and 8,500 for intonated speech).[5.59d]

In terms of audio output and speech synthesis, Bhimani et al. (1966) stress the importance of developing efficient means for automatic conversion from the character sequences necessary for orthographic representation of a word to the phonetic equivalent of that word.[5.59e] Other examples in this area include the work of Rabiner[5.59f] and that of Lee.[5.59g] The converse of this problem, that of "spelled speech",[5.60] is also being investigated.

In the area of speech compression, in addition to examples cited in an earlier report on information acquisition, sensing, and input, the following is to be noted: "Although audio communications is a slow form of information exchange, advances have been made in the production of audio tapes that permit more information to be recorded per unit of time. The President's Committee on the Employment of the Handicapped, through the Division of the Blind of the Library of Congress, is encouraging compressed speech research because it promises to provide a method for recording two to three times as much information per linear inch of tape without distortion or loss of comprehension. Direct access to stores of audio information in libraries offers inexpensive and practical method for updating information frequently and distributing it to both the sighted and the blind over established telephone networks." (Becker, 1967, p. 8).

Two final special cases of audio output should also be mentioned. They are those of the use of the computer to produce musical tones[5.60a] and of computer-assisted music research and composition. In a recent review, Forte (1967) indicates the following principal areas of interest: experiments in auditory perception, the study of musical "gram-

366-108 O - 70 - 3

mars" in order to produce "new" music in a specified styple, music analysis as applied, for example, to pattern recognition procedures for the determination of the style characteristics of a particular composer or period, and the computer development of original musical compositions.[5.60b] A somewhat less exotic example is provided in experiments designed to use computer audio output to teach correct pitch to singers. [5.60c]

A specific example of multiple input-output modes as applied to music research is provided by Teitelman as follows: "The standard teletype of the DEC PDP–6 has been augmented by an 88 key piano keyboard which is connected directly to the computer. Thus the user can play a melody, hear what it sounds like—as performed by the PDP–6—and also see the score displayed visually on the screen. He can then edit the score, using the light pen, the teletype, or the piano keyboard, and hear it played again. Programs are being written to allow the user to request the computer to fill in harmony to a particular melody, or to construct variations on a theme and to play them back to the user." (Teitelman, 1966, pp. 16–17). Still other intriguing possibilities lie in the development of three-dimensional data processing and display techniques, color, and motion picture outputs, to be considered next.

5.2.2. Three-Dimensional, Color, and Motion Picture Outputs

It is noted first that "motion pictures, 3D, and multicolor displays via color separation represent practical capabilities in addition to the more common forms of plotting and printing." (Peterson, 1966, p. 131). Three-dimensional data processing, manipulation and display is of considerable current interest not only for machine-aided design purposes,[5.60d] but also for direct scientific and engineering findings. For example, a paper by Serlin (1966) considers the use of three-dimensional computing and plotting techniques in terms of the partial differentail equations involved in the cooling of a thick glass slab.

Levinthal (1966) has developed techniques for sequential display of two-dimensional output images in such way as to simulate the on-line presentation of the three-dimensional model of a protein molecule.[5.61] Again, a computer-display system may be used in studies of human perception, such as perceptual masking phenomena in sequential perception. (Mayzner and Tresselt, 1966). Tate comments: "Understanding of three-dimensional structure is an essential part of the growth of science. Greatly increased attention must be focused on developing the needed systems for storing the data available in the literature and manipulating the stereochemical details for study." (Tate, 1967, p. 296).

Output representations of three-dimensional data may be either mechanical, as in a spatial data plotter,[5.62] or they may be two-dimensional graphic displays involving variable perspective views and systematic rotation about an indicated axis.[5.63] In the latter case, there may be interesting requirements for handling problems of 'hidden lines'.[5.64] The hidden line problem has been further attacked by Loutrel (1967) and Appel (1966), among others. In addition, Appel (1968) has reported on techniques for machine-generated shading or toning of drawings.[5.64a] Perspective manipulations, shading, and display also provide representations of the variable depths of objects in space.[5.65]

Investigations into three-dimensional data displays include questions of applicability to air traffic control operations,[5.66] to the possibility of creating half-tone, 3-D photographs of conceptualized shapes and objects,[5.66a] to visual simulations,[5.66b] and to the plotting of three-dimensional contour maps of the moon's surface.[5.67] Denil (1966) reports on the development of a design language (DLI), which involves a prototype computer system to handle the design of three-dimensional objects.[5.67a] Beyond this, there are possibilities for *n*-dimensional display of hyperobjects. In the latter case, the investigator concludes: "The importance of the techniques presented . . . is the use of a digital computer to generate visual displays of the three-dimensional projections of the hyperobjects. Such displays of rotating hyperobjects could be produced most efficiently by a computer since the projections and drawing would be too tedious and impractical to produce by any other method. Although no actual mental visualization of the fourth dimension resulted from the computer-generated displays, it was at least possible to visually display the projections and be puzzled in attempting to imagine the rigid four-dimensional hyperobjects." (Noll, 1967, p. 473).

As of several years ago, Rosa reported that questions of color, three-dimensional data display, and size of display were matters of continuing controversy and concern.[5.68] For effective radar and sonar screen displays, many different colors may be required.[5.69] On the other hand, as Hobbs points out, difficult design compromises may be required to achieve good performance,[5.69a] and Baker and Rugari indicate that desired capabilities have yet to be achieved.[5.69b]

A color display device, developed by the Digital Equipment Corporation for the Air Force Cambridge Research Laboratories, uses a 3-gun tube to plot designated points on a 512 x 512 raster. Mazzarese (1965) reports that: "Color has proven particularly useful at AFCRL in filter design studies, which require overlaying graphic information corresponding to different ways of manipulating raw data. Different colors can code different parameters, or varying intensities of one color can show the changes with time of one value."

Further, "the National Aeronautics and Space Administration has awarded the Philco Corp., two contracts to develop an experimental color television display system for possible use in the mission control center of the Manned Spacecraft Center in

Houston." (Electronics **38**, No. 18, 40 (1965).) Mahan (1968) reports on developments at ITT, Philco-Ford, General Electric, and Sylvania[5.69c] while Hartsuch (1968) mentions RCA and Crosfield Electronics.[5.69d]

Then there are possibilities for hybrid displays, such as the following: "One intriguing prospect is a hybrid display—a wall type panel made of solid state materials that emit light when activated by a light beam that is deflected electrically. Such a system would combine the advantages of the two principal approaches to optoelectronic display: the higher resolution and more modest switching requirements of light-beam 'writing', plus the multicolor capability, higher reliability, brighter light and lower power consumption of panel displays." (Soref and McMahon, 1965, pp. 56–57).

Knowlton (1964) describes an ingenious technique for computer generation of animated movies, such as those that might be desired for psychological experiments or for expository educational films or for visual display of computer processing results including the dynamic drawing of flow charts or wiring diagrams.[5.70]

Another example of motion picture output is cited by Gomolak in connection with "electronic draftsman" applications.[5.71] More recently, at Bell Laboratories, animated movies have been machine-generated with respect to the effects of different gyroscope constraints on satellites.' (Noll, 1966, p. 143).[5.72] Then there is the VISTA system (Visual Information for Satellite Telemetry Analysis).[5.72a]

It is to be noted with respect to three-dimensional and dynamic displays that: "General three-dimensional graphical communication, which deals with arbitrary surfaces and space curve intersections, presents many difficult problems; the beginning has been modest and much work remains before the complete graphical communication problem is solved" (Johnson, 1963, p. 347), and that: "The matter of three-dimensional displays is closely allied to the problem of dynamic display and is still a matter of concern." (Rosa, 1965, p. 413).

5.2.3. Multi-media and Special Purpose Direct Outputs

In a 1967 lecture, Mayeda discusses as a new objective of system design the development of multimedia networks, pointing out that, with the exception of certain military and intelligence applications, most information processing systems have been "single path", but that new network requirements will necessitate the use of information processing technologies in combination as well as the "mixing of normally incompatible media into one information transfer system." (p. 4).[5.73]

In addition to the varied combinations of textual, visual, and audio output presentations stressed by Mayeda (1967), a special purpose output mode may be required, involving encoded tactile-pattern messages. For example, equipment providing tactile means for the reception and perception of speech dates back to the "Teletactor" developed by Gault and Crane at the Bell Telephone Laboratories in 1928. Following the development of vocoder techniques (Dudley, 1936) a tactile output vocoder was built by Levine and others at M.I.T., in the period 1949–1951.

A tactile vocoder at the Royal Institute of Technology is designed along lines that are similar to these earlier lines. First, it uses an amplifier to enhance the speech signal as it is received and then passes it through a differentiator to provide high-frequency emphasis. The signal is next divided by means of overlapping filters into ten channels of different center frequencies. The output signals from each channel are rectified and smoothed to provide a control voltage. Next, in turn, each of the ten control voltages modulates the amplitude of a 300-cycle per second sinusoidal signal. When these signals have been amplified and adjusted for channel sensititivity, they are fed to ten bone-transducers serving as vibrators to stimulate the tips of the user's fingers from left to right across both hands in the order of the lowest to the highest channel. (See Pickett, 1963).

Then we note that: "Researchers at Stanford Research Institute under Dr. James C. Bliss have devised a 12 x 8 array of air jets which, under control of a CDC 160–A, is capable of transmitting a perceptible message." (Datamation **9**, No. 11, 61 (1963).)

The potential multiplicity of different input-output modalities may be illustrated by two examples. First, the future potentialities of man-machine interchanges between verbal and graphic representations of chemical structure and other diagrammatic information are just beginning to be explored. Such possibilities are of considerable interest in such areas of application interest as studies of interactions of chemical structures with biological effects. Some of the possibilities may be exemplified by the following case: Without having undertaken a prior literature search, the researcher has synthesized a new steroid compound in the laboratory. He prepares a chemical code notation and/or structure-connection-table listing as input. As a result, he receives:

a. An indication as to whether or not his presumably "new" compound has been previously reported in the literature and, if not, whether it is possibly patentable.
b. A two- and preferably three-dimensional display of the structure he has described. This may or may not be over-written in terms of coincidences with previously recorded information. By pointing at specific subsets of the diagram, he will direct the system to retrieve and report all available data with respect to observed physical characteristics and biological effects of known compounds containing this specified subset structure.
c. He may then add to or delete from listings of multiple-substituent possibilities at variable locations of attachment to the given nucleus,

and request display/report of the consequences in terms of previously known results.

As a second example, a reading-machine system under development at M.I.T., "will include an opaque scanner for the sensing of printed matter, real-time data-processing facilities for real-time scan control, for operating upon the data, for controlling tactile and auditory displays, and for monitoring and analyzing the performance of human subjects. In its most sophisticated mode of operation, the system will recognize printed characters and generate artificial speech. A less sophisticated output mode will utilize Braille for tactile sensing and spelled speech for auditory reception. In its simplest mode of operation, the system will simply reproduce, as tactile patterns, the black-white shapes sensed by the scanner, without automatic character recognition. Between the simplest and most sophisticated modes, there lies a spectrum of intermediate modes." (Quarterly Progress Report No. 80, Research Laboratory for Electronics, M.I.T., 217–218 (1966).)

Then there are developments in what has been termed an ". . . Interaction Screen". This may be achieved by an electronic system "consisting of five major components: two consoles, one for each subject, through which, by operating dials and switches, they interact with one another; an experimenter's console for monitoring subjects' interaction; a control unit for altering the response possibilities open to the subjects; and a card punch that records all interaction by both subjects." (Sawyer and Friedell, 1965, p. 447). Beyond such interaction capabilities, large scale and high resolution dynamic displays may be desired for group interaction with processor systems.[5.74]

6. System Output to Microform and Hard Copy

In the preceding section, we have considered direct output and display primarily as associated with Box 5 of Figure 5. In fact, this arbitrary association is indicative of some of the difficulties of presentation in this and other reports of this series, since in many cases the distinction between these direct outputs and those outputs that follow post-processing operations (Box 13) is entirely artificial. (Certainly the question of a multiplicity of output modalities and of multi-media output presentations is at least as pertinent to Box 14 as it is to Box 5.)

However, the intention in the preceding section was intended to emphasize the possibilities of direct, on-line interaction between the user and the system. In particular, as previously noted, new problem-solving capabilities are offered by advanced information processing techniques, especially in the form of a two-way process of graphical input and output and of effectually on-line communication between the problem-solver and the machine so that, at the man's own pace, he is able to study the effects of modifications and changes by having the results displayed to him almost instantaneously.[5.74a]

By way of contrast, in discussing the areas of R & D concern with respect to Box 14 of Figure 5, we will consider those output techniques, media, and products that may be produced either on-line or off-line and that may often involve the use of various intermediate media of storage and/or transfer. It is of course also arbitrary to consider the system output products of Box 14 prior to discussion of the special post-processing operations (Box 13) that typically precede them (this is also true with many if not all of the techniques and products considered in association with Box 5). However, since post-processing operations such as transliterations and re-formatting are often closely dependent upon choices of specific output modes, we have deliberately deferred discussion until we have covered some of the remaining output mode possibilities. Thus, in this section, we shall be concerned with computer-based microform recording and direct output transmission, with printing, photocomposition, and character and symbol generation, and with requirements for hard copy output.

6.1. Microform Recording and Direct Output Transmission

As we have seen in consideration of file media and data storage techniques (Section 4), there are both advantages and disadvantages of either digitalization or of document miniaturization in facsimile form for many different purposes. In many situations a judicious mixture of the two approaches may be the best solution.[6.1] To the extent that document or data miniaturization processes are adopted, however, there are specific questions of direct output, post-processing operations, and delayed or off-line output. These questions include output recording of processed material to microforms, clientele requirments for hard copy, quality of display and reproduction, output via transmission lines in various communication systems, and on-line alteration of microform images.

An inportant recent trend in microform recording has been an increased coupling of computer processing to either off-line or on-line outputs into one or more types of microforms.[6.2] In a 1965 survey, Kornblum predicted that microfilm, microfiche, and microfilm aperature card techniques would have increasingly more challenging applications, specifically including on-line tie-ins to computer systems and to multiple-access data banks. He cited, in particular, the evaluations of the Micro-Data Division of Bell and Howell and of NCR.[6.3]

By 1967, it could be specifically suggested that: "The genuine advantages of microform computer output indicate that all output, except possibly that

used for debugging purposes, should be converted directly to some sort of microform, eliminating the intermediate stage of hardcopy. Indeed, IBM's listings of systems programs produced for its customer- and systems-engineers are stored on microfiche. The ease and cost of getting hardcopy when essential will naturally depend on progress in the microform reader/printer technology; the high stakes involved in being able to handle computer output should encourage such progress." (Van Dam and Michener, 1967, p. 192).

Equipment such as the Stromberg-Carlson SC 4020 microfilm plotter [6.4] and later "Micromation" equipment (Kalagher, 1968, p. 37),[6.4a] an IBM system [6.4b] and the 3M Electron Beam Recorder [6.5] are commercially available for such purposes, offering in the latter case speeds of up to 60,000 lines per minute. At Bell Laboratories, such an output mode has been available since 1961, and it now includes computer-generated movie capabilities.[6.5a] In addition, a package of FORTRAN programs has been developed that provides for drawings of orthographic views of combinations of plane and quadric surfaces that are output to a microfilm recorder. (Weiss, 1966).

On-line *modification* of displayed microform-recorded graphic images is specifically included in many machine-aided design and machine-assisted problem-solving applications, including the previously mentioned DAC (Design Augmented by Computer) system,[6.6] and others (see p. 23).

A first factor involving the quality of display and subsequent copy reproduction of materials processed and stored as microforms involves the quality of the input material.[6.6a] A second factor involving quality of display and reproduction is that of proper maintenance of equipment [6.6b] as well as of the microforms themselves.

From a systems design point of view, however, the most critical factors are those reflecting client willingness to accept and use the products and processes of microform techniques. For example, it has been quite widely assumed for some years that the use of microforms for documentary and library reference purposes is generally unacceptable to scientific and technical users. With improvements in the availability of microforms and in the technology of use however, there is now evidence of growing acceptance and in some cases of certain advantages to the user.[6.7]

Nevertheless, the systems planner and designer must still address himself to the questions of how convenient, how compact, and how portable available viewers having good quality legibility are? Can hard copy, enlarged printouts be obtained either directly or indirectly on a selective basis from such devices or must there be resort to separate processes involving other equipment? Further, it has been noted that "the general problem of a satisfactory hand-reader for microform still remains to be solved." (Council on Library Resources, 1966, p. 52). Wooster, (1968) however, suggests a "cuddly" microform reader, as shown in Fig. 7.

With respect to direct output transmission via various types of communication links, it is noted that Long Distance Xerography techniques developed by Xerox can be used for transmission of graphic materials from computer-based stores,[6.7a] as can other types of scanning converters transmitting to remote facsimile recorders.[6.7b]

A more recent Xerox development is the Graphic Terminal Hardcopy Printer, used at the Bell Telephone Laboratories in conjunction with a computer-driven data display system.[6.7c] A special-purpose device, the Microteleviser, providing for the remote viewing and continuous focus magnification of microfilm images, was introduced by General Precision, Inc., at the 1965 WESCON exhibition.

Output via closed-circuit TV systems is also presently limited primarily because of high costs for use of coaxial cable transmission. However, various trials of such systems have been and are being made—for example, the Council on Library Resources has supported studies of the "Telereference" system involving closed-circuit TV and a remotely controlled card manipulator for multiple external references to a library card catalog at a central location,[6.9] a closed-circuit system has been installed for the Lake County libraries so that the common collection can be appropriately shared,[6.10] and a laboratory use of such a link for graphical presentations of computer output has been reported by Neilsen.[6.11] In addition, Brookhaven National Laboratory operates a network for video storage and display at the local stations.[6.11a]

Examples of commercial developments include Remstar, which couples closed circuit TV transmission with automatic records retreival equipment.[6.11b] Then, in Great Britain, a patent (No. 997,946) has been granted to Pye, Ltd., for a system that converts normal high-speed TV signals into low speed signals generated with a slow scanning speed and occupying a narrow bandwidth (see *Electronics Weekly*, No. 258, for Aug. 11, 1965). Dixon Industries, Inc., has developed a video system, VIDEO–IR, allowing remote transmission via slow-scan methods over ordinary telephone lines, and offering a unitized tape record the size of a punched card to hold up to 150 pages, as well as tape reels. (Sci. Inf. Notes **7**, No. 1, 2 (1965).)

6.2. Printing, Photocomposition and Computer-Controlled Character and Symbol Generation

The earliest and still most common form of output of information processing system results is that of typing or printing. In the past few years, increasingly automated techniques have emerged for use in publication and printing processes. These range from use of direct computer printouts, using high speed, but low quality printers, through computer-generated tapes that drive automatic typesetting operations to batteries of low speed composer-printer devices, to computer control of high-speed

FIGURE 7. *Proposed microform reader.*

composition systems that do provide output of good typographic quality. There are obviously continuing problems of advanced system design, in terms of appropriate comprises between speed and quality.[6.12]

6.2.1. Line Printers

In general, direct, on-line printouts from information processing systems are made at high speed, but with monocase limitations,[6.13] fixed intercharacter and interword spacing, and poor utilization of paper.[6.14] In the case of some chain printers, such as the IBM 1403 [6.15] and the Potter Chain Printer,[6.16] somewhat larger character sets than the single case set can be accommodated. Then it is to be noted that "use of 2-case print mechanisms on high-speed computer printers for the display of extended chemical character sets has been under joint development by IBM and Chemical Abstracts." (Burger, 1964, p. 2).

In addition, it should be noted that "printing speed for these [chain] printers depends both on the information to be printed and the character arrangement. Since most printing applications use some characters more often than others it may be possible to increase the printing speed by repeating high usage characters on the chain more frequently than low usage ones." (Eichelberger et al., 1968, p. 130). Further, "given character usage statistics we can (1) reliably estimate printing speed for a given character chain arrangement and (2) improve the arrangement so as to increase the average printing speed." (Ibid, p. 136).

There are continuing trends for higher and higher speed of printer output, especially in the area of non-impact printing devices, since, as Becker points out, 1200 lines per minute is "about the maximum speed of a line printer because there is a limit to the firing time available for mechanically operating a print hammer." (Becker, 1967, p. 2).[6.17] Advanced hardware techniques for output printing include a thermal imprinting development by NCR for the U.S. Army Electronics Command.[6.17a]

In a brief 1965 survey of non-impact printers, Webster notes first a facsimile process technique which forms a latent character image on electroconductive paper by pulsing selected wires in a matrix of styli. The visible image is formed by liquid or power toner that adheres only to the image area and is bonded by heat and/or pressure. Representing this approach today are small serial devices such as Motorola's TP–4000, and "high-volume printers such as the Radiation 'Super-Speed' printer—over 31,000 lines per minute".

Planned variations in the TP–4000 teleprinter equipment also illustrate new developments of interest in the multiple access and man-machine interactive systems. "This new teleprinter will . . . provide a single facility for the human operator to make inquiry of a computer at his maximum but plodding rate of 10 to 15 characters per second, and receive his answer back at a rate of 300 characters per second." (De Paris, 1965, p. 49).[6.18] Another example is the development of Miniaturized Techniques for Printing, or Miniprint, by NCR.[6.18a] On the other hand, higher speeds may result in the loss of visibility for the user of an on-line terminal.[6.18b]

Nisenoff reports that, as of 1966, "several developments were undertaken to produce ultra-high-speed printing mechanisms of a non-mechanical nature. Radiation, Inc., for example, built an electrostatic printer which required special electrosensitive paper. With the paper moving at nearly 100 inches per second, a maximum printing rate of 60,000 characters per second (500 lines per second or 30,000 lines per minute) was attained. The cost, however, was high for general use of this type of subsystem." (Nisenoff, 1966, p. 1824).[6.18c]

6.2.2. Photocomposition and Electronic Character Generation Techniques

A major type of non-impact printing technique is represented by the various types of photocomposition equipment. By contrast with impact printers, with other types of non-impact printing, and with hot-lead typecasting machines, the photocomposition techniques involve the transfer of optical images of characters from a negative master to a photographic emulsion, with suitable provisions for illumination, image magnification or reduction, and positioning. Many techniques and configurations of mechanical, optical and electronic devices and developments have been employed for such purposes.

Typographic quality output is achieved in photocomposition techniques by the automatic selection of the right one of several sets of characters, by point size adjustments for the individual character including those necessary for subscripts and superscripts,[6.18d] by controlled positioning of the character as projected, and by insertion of special symbols and characters.[6.19]

The generation, accurate placement, and permanent storage of hundreds or thousands of high-quality symbols per second presently require that optical-photographic techniques be employed, since the speeds are too great to permit mechanical symbol selection. Photography on film or paper is the currently preferred recording method, although other graphic storage techniques, such as electrostatic, thermographic, thermoplastic, photochromic or video signals on magnetic tape offer alternative recording possibilities.[6.20]

More than two decades of development in photocomposition techniques (from the Higgonet and Moyroud "Lumitype" and "Photon" patent applications of 1945) have culminated as of today in a wide variety of available devices in a broad range of costs and performance characteristics. At one extreme, we find 6–10 character per second devices. At the other end of the speed spectrum is the Benson Lehner Transdata system with a theoretical text composing speed of 62,500 characters per second, but with a character set (or "vocabulary") limited to less than 100 characters or symbols. The intermediate speed range is bracketed by the Photon

900 series (300–500 cps) and the specified Linotron rates of 1,000–10,000 cps. Hartsuch reports 1967 developments by Photon, Fairchild Graphic Equipment, American Type Founders, Alphanumeric Inc., Harris-Intertype, and K. S. Paul and Associates, among others.[6.20a]

Among the electronic character generation techniques noted in Webster's 1965 survey were the A. B. Dick Videograph,[6.21] the Stromberg-Carlson Charactron shaped-beam tube,[6.22] and "the . . . little-known *Xeronic High-Speed Computer Output Printer* developed by Rank Data Systems Division . . . Character formation is by a pair of cathode ray tubes which form the latent image on the charged paper, which is developed by a continuous xerographic system. The 'form' repertoire is held on a strip of film which is superimposed over the frame of variable information." (Webster, 1965, p. 45).

Character generation techniques for high quality as well as high speed composition are employed in the Linotron system,[6.23] in RCA developments,[6.24] and in the Digiset equipment developed by Dr. Rudolf Hell.[6.25] An entry of Bell Laboratories is described by Mathews and Miller (1965) as having the following graphic arts display characteristics: "The unit can produce on a single scope face high quality printing with as much as 200 lines of 350 letters each . . . at speeds of 500 to 5,000 characters/second. . . . Since the image is described in complete generality digitally, line drawings, mathematical equations, musical scores, and an unlimited number of type fonts can be produced by the same, completely standard, means." (p. 397) More recent developments in high speed character generation for phototypesetting also include the IBM 2680 CRT printer.[6.25a]

6.2.3. Computer-Controlled Typographic Composition

Thus, in the past several years, three major, and often closely interrelated, developments in hard copy production technology have gained considerable momentum. These are: the development of techniques for computer-based typesetting, including automatic justification and hyphenation; the further improvement and widespread use of photocomposition techniques, and the development of both off-line and on-line devices for high speed character and symbol generation, including the recent breakthrough in "computer calligraphy", notably, at the U.S. Naval Weapons Laboratory, Dahlgren.[6.25b]

The automation of the traditional compositor functions is well on its way toward revolutionizing the printing industry. Overviews of this field have been provided by Barnett (1966), by publication of the Proceedings of the two Computer Typesetting Conferences (the Institute of Printing, 1965, 1967), and of a 1965 Symposium sponsored by the Center for Technology and Administration of The American University (Hattery and Bush [eds.], 1965), and by a Symposium held at the National Bureau of Standards (Lee and Worral [eds.], 1968), as well as by the Stevens and Little review (1967).

It is to be noted in particular that "the Government Printing Office was instrumental in the development of computer programs and production techniques which have made it possible to utilize the most recent developments in printing technology and to apply automation to the publication of . . . [the] latest edition of the Library of Congress subject heading list. This is the largest single publication which has been produced by the Government Printing Office using computers and photo composition." (L.C. Info. Bull. **25**, 612, 1966). Further, there are even computer typesetting procedures designed for publication of computer language specifications, such as that developed for Autocode AB, in Sweden. (von Sydow, 1967).

The field of typographic-quality composition and printing actually comprises several quite different technologies. However, a number of these techniques may be made to converge in the design of a single large-scale system. At one extreme, a skilled, highly trained operator must perform all of the compositor functions (spacing, leading, horizontal and vertical justification, hyphenation, page makeup) required to operate typesetting equipment; at the other extreme, text copy with or without font, style, size, or format specification can be processed with a high degree of automation through all the operations that are necessary to produce type or plates set for printing.

Among the pertinent technologies are: special-purpose devices or computers to provide justification, re-spacing and hyphenation information automatically;[6.26] photocomposition developments; electronic character generation devices for both on-line and off-line applications, and the programming of general-purpose computers to accomplish the type compositor functions.

Improvements in size of character repertoire and provisions for rapid switching between character sets under automatic control are under active development. Some systems incorporate possiblities for program-controlled, light-pen inserted, or reproduced-from-storage interpolations of graphic material with text, ranging from formatting grids and lines (in order to separate or to emphasize tabular or columnar matter) to the incorporation of reproduced photographs with half-tone fidelity.[6.26a] Other combinations may permit the intermixture or superpositioning of pre-recorded graphic information (including pictorial data) with that of text or graphics generated effectively on-line.[6.26b] For example, the new Photon 901 allows variable character density, together with other improvements of the 900 (or Zip), and in addition provides for the insertion of graphics from projected slides.[6.26c]

Going beyond the direct composition onto the page of two-dimensional symbols, many applications of the future will demand the automatic insertion of previously stored graphic material such as drawings, illustrations and photographs and of

similar material received via communication means such as facsimile. Actually, this type of sophisticated output has been investigated in several quite early projects,[6.27] and it has been claimed that "there appears to be no real technical barrier to the simultaneous or practically simultaneous composition-imposition of both text and graphics." (Duncan, 1964, p. 135).

The Linotrons and related equipment built for the Air Force will provide for the generation of graphical material, such as line art illustrations, continuous tone illustrations, and screened halftone illustrations in a separate video display system, with optical mixing of the lexical and graphical material.[6.28] Beyond such questions are those of "Computer Calligraphy" (Hershey, 1967), including problems of computer-controlled composition of chemical structure diagrams and mathematical formulas, to be considered in a more general discussion of character sets and display terminal design requirements in a later report in this series.

As of 1967, then, the computer has demonstrated capabilities for eliminating the need for complex compositor skills on the part of keyboard operators, for providing significant increases in the speed with which type composition functions may be carried out, and for keeping pace with those developments in electronic photocomposers that promise graphic arts quality typesetting at speeds of several thousand characters per second and the superimposition of line art, screened halftones, and continuous tone illustrations.

6.3. Hard Copy Reproduction

It is obvious that direct printout, delayed printout, photocomposition, and symbol and character generation techniques can provide the typical system client with hard-copy versions of the information processed by a system or contained in or retrieved from its files. In other cases, however, the primary system output (whether in Box 5 or Box 14 of Figure 3) is some type of visual display of complete items or their surrogate representations which the user scans. Such displays may also be accompanied by address-locators such that the item in its entirety may be retrieved or reproduced in facsimile from its location in physical storage. In addition, the option of hard-copy or facsimile reproduction may often be desired from the system response and display as such.[6.28a]

In particular, the provision of hard-copy retrieval options is important in most information selection and retrieval systems involving storage of documents and data in microforms. While some controversy exists with respect to the extent and urgency of client requirements, user satisfaction considerations would appear to dictate continuing agreement with such commentators as Mikhailov of VINITI in 1962, "the production of a large number of copies directly from microfilm must be made possible . . ." (1962, p. 51) and of Licklider with respect to an on-line system of the future: "There should be a way to capture any frame of the display in the form of 'hard copy', and the hard copy should be coded automatically for machine filing, retrieval, and redisplay." (1965, p. 94). It is, however, important to determine the extent to which hard copy options are actually needed, rather than merely desirable.[6.29]

In terms of technological developments related to hard-copy output options we note various types of electrostatic, magnetic, and smoke photographic methods.[6.30] We note further that RADC has awarded Xerox Corp., a contract to build a *selective* photocopier that will separate printed text from illustrative and pictorial material.[6.31] Another example is the Bolt, Beranek and Newman "Symbiont", a computer program system designed to facilitate the use of technical documents by students that includes an automatic note-taking and copy feature for student-selected portions of text (Bobrow et al., 1966). Thus, photocopying techniques continue to be an important means of system response. However, such techniques are encountering steadily increasing difficulties in terms of coping with the steady growth in volume of demand. There have been complaints, moreover, that continuing development efforts are required in the conversion of microfilm to hard copy, particularly in the areas of speeding up the processes and reducing the cost of copies.[6.31a]

6.4. Post-Processing Operations and Special Forms of Output

In the case of computer typesetting, photocomposition, and character generation techniques, the post-processing operations of Box 13, Figure 3, are represented first by formatting processes to provide horizontal and vertical justification, hyphenation, and the like.

On-line formatting in terms of output through either computer-printer or computer-controlled typesetting devices is typically limited to intra-line and interlinear spacing control. As we have seen, controlled variation of printing weight may also be available through repetitive overprinting of the same character in the same spatial position on the output media (e.g., special chain-printer arrangements). In certain ingenious applications even so limited a device as the high-speed line printer has been used to simulate gray-scale variation in two-dimensional graphic representations by choice of heavily "inked" character symbols to fill in darker areas and those characters involving relatively less weight for the lighter areas. With the introduction of electronic generation and display techniques, however, on-line formatting potentialities take on much more versatility.

Other than for formatted printout, output response may be required at several different levels. Post-processing operations will thus involve re-arrangement, re-formatting and transliteration or translation of the direct results of processing, matching, selection, and/or retrieval operations into forms and into

languages required for subsequent presentation, transmission, and use to the system clientele.[6.31b] For example, Press and Rogers describe TRACE, which "is a program with extensive capability to edit, reconfigure, and display multivariate data." (Press and Rogers, 1967, p. 37).[6.31c]

In such post-processing operations, for another example, we note a speech recognition requirement: "The speech-recognition device, after having identified phonetic stretches on the basis of their perceptual characterisitics, must transform them into strings of linguistic signs . . ." (Garvin, 1963, p. 113). As we have seen in an earlier report, speech compression requirements are directly related to problems of achieving more efficient and more economical use of communication and data transmission links.

Postprocessing operations may also be applied in order to provide special forms of output that are dictated for particular potential applications; transliteration into Braille,[6.32] into synthetic or prerecorded spoken messages, and translation from orthographic word records into phonemic form,[6.33] for example. Nelson (1965) suggests a relatively simple device for coupling blind users to on-line text libraries via a Braille display.

Another special form of output for the handicapped is to produce from information processing equipment applied to speech analysis rapid displays of both spectrum and frequency analyses so that a totally deaf child can see the results of his attempts to speak and compare them with desired performance in order to make rapid adjustments.[6.34] "Spelled speech" is another output variant that is intended to be used in connection with the development of reading aids for the blind.[6.35]

Post-processing operations will also include, as appropriate, various summarizations and condensations of the information that has been processed or retrieved. For example: "Large-scale data-processing systems have been planned in which the input is in the form of on-the-spot observations in special formats. Retrieval is then required, not just of the observations themselves, but of [inferences] from them, through conditional search, summing, averaging, correlating, finding maxima, reporting sudden changes of state, etc." (Bohnert, 1963, p. 155). Yet, as of today "too many systems are designed to display all the data, and not to display only the data needed for the decisions the system is called upon to make." (Fubini, 1964, p. 2).

Finally we note that system outputs based upon post-processing operations will potentially involve feedback information, such as activity analysis, or the following: "A programming capability is to be provided which, when initiated, will tally the number of requests for specified combinations of data items thereby enabling analysis by operating personnel, leading to refinement of the output formats and output request procedures through experience with the system." (Geddes et al., 1963, p. 23). In particular, output becomes input again in many of the advanced techniques that have been investigated and demonstrated. More expecially, feedback information, whether generated by man or by machine, may control various "threshold" settings as shown in Figure 1 and other figures in this and other reports in the series.

7. System Use and Evaluation

With respect to Box 15 of Figure 3, that of use and evaluation of information processing system products, we will consider many of the current problems and difficulties in more detail in another report in connection with the severe case of evaluation of information storage, selection, and retrieval (ISSR) systems. However, we note here a few examples of current concern with problems of systems evaluation methodology generally.

Basic problems of evaluation methodology relate first to the size, complexity, and open-endedness of the systems themselves; the number of interdependent variables; the difficulties of defining and isolating variables, and the amount of data to be collected and processed.[7.1] In particular, it is noted that: "Information collected about a very large system may become obsolete faster than it can be collected." (McCarn, 1965, p. 95).

It also still appears obvious, as of 1967, that "comparison and evaluation of systems are still very hazardous, because of the many variables that enter into the design of any particular system and the fact that the design of any system is decided to some extent on specific objectives and somewhat unique combinations of objectives. It is doubtful that the comparative tests that have been made or that are planned can decide the relative merits of systems for general application. They can only help to decide on the merits of certain particular systems for certain particular applications. Hence there is real danger in drawing general conclusions from experience that is as yet too limited." (Lee and Campbell, 1959, p. 1555).

Current techniques for system evaluation pose many difficult problems and have been severely criticised as to their present inadequacies. For example, to Bryant's complaints about 'lack of well-defined objectives' and 'lack of meaningful models', (1966, presented in 1964) Davis adds the following difficulties: "Uncertainty concerning measures of effectiveness", those of determining system scope, and lack of quantitative evaluation criteria, as well as those of security or proprietary interests and those where disinterest in evaluation results because there are no obvious penalties for poor system design. (Davis, 1965, p. 81).

An obviously difficult problem is that of identifying meaningful evaluation criteria.[7.2] Even with obvious

objective system performance criteria, such as cost, equipment reliability, or response time, many practical difficulties are encountered. Both true costs and true benefits are often difficult or even impossible to measure. True costs, for example, certainly include those of the personal time and effort required of the potential user, while true benefits may be intangible, for example, in the sense of the negative benefits of not missing pertinent information.

The questions of client-utilization of system products, with special attention to the interrelated problems of system evaluation, are of particular concern. We are faced, first of all, with the lack of quantitative measures of effectiveness, with subjectively rather than objectively determined performance factors, and with a variety of uncontrolled variables involving human factors.[7.3]

Research and development requirements in the area of system evaluation involve the establishment of research corpora, "core" problems, and "test-bed" data banks against which comparative experiments may be run. Better system models and more precisely selected and defined measures of performance effectiveness are obviously required. Morey and Yntema emphasize that: "As the economic and operational implications of man-computer systems loom larger, the need for more powerful evaluation tools and techniques increases. System testing, as the prime source of data upon which any evaluation is based, shares this need for improved methodology." (Morey and Yntema, 1965, p. 349).

We need both better measures of system effectiveness and the development of "core" or "benchmark" problems for purposes of test. As Davis comments: "Measures of effectiveness and use of test problems are complementary rather than being substitutes one-for-the-other. Test problems, simulating the actual system usage, will show up system defects not detectable through the application of measures of effectiveness." (Davis, 1965, p. 82).

Nevertheless, it is to be emphasized that "unfortunately, no real guidelines are available which could be used in the design of evaluation procedures, and most of the methods actually proposed are based on *ad hoc* rules which stress theoretically desirable features, and do not concern themselves with practical questions. As a result, much of the proposed methodology cannot, in fact, be implemented reasonably in a test situation." (Salton, 1965, p. 201).

Even more discouraging, perhaps, is the opinion of some investigators that the development of evaluation methodology itself is even less advanced than that of system analysis and testing. Thus, "one can raise reasonable doubts, however, that the development of evaluation methodology has kept pace with the development of the systems." (Morey and Yntema, 1965, p. 349). Further, "progress in designing and applying information handling systems has outraced progress in evaluating their performance. As system complexity has increased, the relative adequacy of existing evaluation tools has decreased." (Calingaert, 1967, p. 12).

We may also concur with the opinion of Blunt that "the system engineer presently lacks sufficient tools to efficiently design, modify or evaluate complex information systems." (Blunt, 1965, p. 69). Several of the new tools that are being developed include formal modelling and simulation techniques, but we shall discuss these in terms of overall system design questions, to be considered in the next report in this series.

8. Conclusion

In this second report, a number of developments have been adduced, and a number of areas of continuing R & D concern have been indicated, with respect to processing operations, processor system management, storage, postprocessing operations, and on-line and off-line outputs from generalized information systems. As we have seen, for example, output products involving graphic two-dimensional or three-dimensional and voice response representations of stored data are relatively new but are of increasing importance in on-line, reactive, selection and retrieval systems and, in particular, for systems oriented toward machine-aided design applications. Two-dimensional data outputs are already widely available both in the form of facsimile and TV recordings and transmissions and in the form of dynamic, on-line displays, but these are all areas requiring extensive further efforts and developments aimed, in particular, at lower cost. With respect to hardware requirements alone, Hobbs in his 1966 predictions of hardware developments for the 1970's recapitulates many of the areas of hardware R & D concern that have been indicated in various sections of this report. In particular, he points to the following major problem areas:

"Low-cost, large capacity, alterable on-line storage.
Low-cost, reliable input/output equipment.
Proper selection and organization of storage hierarchies.
Low-cost inquiry/display consoles for man-machine interaction.
Dynamic real-time large-screen displays.
System design and application concepts that minimize input/output operations at the expense of more internal logic and memory.
Improved concepts of increased functional modularity to utilize large interconnected circuit arrays.

Improved automatic fault isolation and maintainability.

Economic associative memories or other hardware techniques to facilitate file access by content.

Protection of data base in multi-computer, multi-user systems with many remote users.

Communications between remote user consoles and the processor, between different processors, and between remote processors and the data base." (Hobbs, 1966, p. 44).

Other considerations, such as those of programming and other software requirements, are also of obvious concern. In many cases, however, such considerations relate to the many interrelated functions of a generalized system and not merely, for example, to input rather than output or vice versa. For these reasons, we will consider overall system design requirements (including problems of system and network design, programming languages and related software developments, advanced hardware technologies, and the like), in a third report in this series.

Appendix A. Background Notes on Research and Development Requirements in Information Processing, Storage, and Output

In this Appendix we present further discussion and background material intended to highlight currently identifiable research and development requirements in the broad field of the computer and information sciences, with emphasis upon processing, storage, and output functions of information processing systems. A number of illustrative examples, pertinent quotations from the literature, and references to current R and D efforts have been assembled. These background notes have been referenced, as appropriate, in the summary text.

1. Introduction

1.1 There are certain obvious difficulties with respect to the organization of material for a series of reports on research and development requirements in the computer and information sciences and technologies. These problems stem from the overlaps between functional areas in which man-machine interactions of both communication and control are sought; the techniques, tools, and instrumentation available to achieve such interactions, and the wide variety of application areas involved.

The material that has been collected and reviewed to date is so multifaceted and so extensive as to require organization into reasonably tractable (but arbitrary) subdivisions. For example, the present report is concerned with problems of management of multiple access systems in terms of processing system service requests, among other topics, but questions of programming languages and other overall system design considerations will be discussed in a separate report.

Other topics to be covered in separate reports in this series will include specific problems of information storage, selection and retrieval systems and the questions of maintaining the integrity of privileged files (i.e., some of the background considerations with respect to the issues of privacy, confidentiality and/or security in the case of multiply-accessed, machine-based files, data banks, and computer-communication networks).

In general, the plan of attack in each individual report in the series will be to outline in relatively short discursive text the topics of concern, supplemented by background notes and quotations and by an appendix giving the bibliographic citations of quoted references. It is planned, however, that there will be a comprehensive summary, bibliography, and index for the series as a whole.

Since problems of organization, terminology, and coverage have all been difficult in the preparation of this series of reports, certain disclaimers and observations with respect to the purpose and scope of this report, its necessary selectivity, and the problems of organization and emphasis are to be noted. Obviously, the reviewer's interests and limitations will emerge at least indirectly in terms of the selectivity that has been applied.

In general, controversial opinions expressed or implied in any of the reports in this series are the sole responsibility of the author(s) of that report and are not intended in any way to represent the official policies of the Center for Computer Sciences and Technology, the National Bureau of Standards, or the Department of Commerce. However, every effort has been made to buttress potentially controversial statements or implications either with direct quotations or with illustrative examples from the pertinent literature in the field.

The author of the present report must apologize for a necessary selectivity and for many inadvertent omissions in coverage. It will be appreciated if specific omissions are called to our attention. It is to be noted that neither inclusion nor citation is intended in any way to represent an endorsement of any specific commercially available device or system, of any particular investigator's results with respect to those of others, or of named project objectives. Conversely, omissions are in no sense intended to imply adverse evaluations of products, media, equipment, systems, project goals and project results, or of bibliographic references not included.

There will be quite obvious objections to this necessary selectivity from readers who are also R & D workers in the fields involved as to the representativeness of cited contributions from their own work or that of others. Such criticisms are almost inevitable. Nevertheless, these reports are not intended to be state-of-the-art reviews as such, but rather they are intended to provide provocative suggestions for further R & D efforts. Selectivity must also relate to a necessarily arbitrary cut-off date in terms of the literature covered.

These reports, subject to the foregoing *caveats*, are offered as possible contributions to the understanding of the general state of the art, especially with respect to long-range research possibilities in a variety of disciplines that are potentially applicable to information processing problems. The reports are therefore directed to a varied audience among whom are those who plan, conduct, and support research in these varied disciplines. They are also addressed to applications specialists who may hope eventually to profit from the results of current research efforts. Inevitably, there must be some repetitions of the obvious or over-simplifications of certain topics for some readers, and there must also be some too brief or inadequately explained discussions of other topics for these and other readers. What is at best tutorial for one may be difficult for another to follow. It is hoped, however, that the notes and bibliographic citations will provide sufficient clues for further follow-up as desired.

1.2 Certain features of the information flow and process schema of Figure 1 are to be noted. It is assumed, first, that the generalized information processing system should provide for automatic access from and to many users at many locations. This implies multiple inputs in parallel, system interruptibility, and interlacings of computer programs. It is assumed, further, that the overall scheme involves hierarchies of systems, devices, and procedures; that processing involves multi-step operations, and that multi-mode operation is possible, depending on job requirements, prior or tentative results, accessibility, costs, and the like.

It should be noted, next, that techniques suggested for a specific system may apply to more than one operational box or function shown in the generalized diagram of Figure 1. Similarly, in a specific system, the various operations or processes may occur in different sequences (including iterations) and several different ones may be combined in various ways. Thus, for example, questions of remote console design may affect original item input, input of processing service requests, output, and entry of feedback information from the user or the system client. The specific solutions adopted may be implemented in each of these operational areas, or combined into one, e.g., by requiring all inputs and outputs to flow through the same hardware.

2. Processor System Considerations

2.1 "Besides being useful to individual users who wish to borrow each other's routines, a sharing mechanism is also useful to a group of users who wish to reference certain segments in common. Such segments might be a set of library routines, or a set of procedures making up a programming language system." (Dennis and Van Horn, 1965, p. 31).

"With such a mechanism [common program-segment use], it is fruitful if the scheduling logic clusters 'like' programs in the schedule or queue and thereby amortizes program-code swap time across many users." (Schwartz et al., 1965, p. 20).

"There are various means of achieving a time-shared system, and the distinctions among them are sometimes quite fuzzy. Clouding the picture even more is the tendency evident in the literature to couple the goal of 'intimate' man-machine communication to one method for achieving time-sharing and then implicitly to associate time-sharing solely with this one method. For example, 'time-slicing', or the assignment of particular segments of time to a given user or problem on a repetitive basis, is a form of time-sharing. 'Dedicated time' modes of operation, where a user is guaranteed a certain percentage of the computer's time in a given period, could be construed as another form. A number of users have indicated that they feel the strongest 'interaction' with the computer when the system operates in the dedicated time mode." (Davis, 1966, p. 224.)

"Time-sharing typically means expense-sharing among a large number of subscribers, with reduced computing costs for many kinds of applications." (Sackman, 1968, p. 1).

"One could say that time-sharing is the use of a multiprogrammed processor for the purpose of permitting a number of users to operate the processor in such a way that each is unaware of the use of the processor by the others." (Collila, 1966, p. 51).

"We may, therefore, expect to see in the next few years a meld of time sharing and multiprocessing, i.e., simultaneous employment of two or more time-shared processors in association with a common memory, which in a sense will be both time-shared and space-shared." (Licklider, 1965, p. 26.)

"By the spring of 1967 . . . there were some 37 systems in operation, 25 research-oriented and 12 commercial systems. These vary from small to large but all are characterized by a central computer and main memory that are time-shared among the users, and an auxiliary storage that is space-shared by the programs of all the users and the systems programs." (Harder, 1968, pp. 235–236).

Weil (1966) provides general coverage of the history and probable impact of time-sharing concepts and systems on the management of data processing operations.

2.1a See, for example, the bibliography compiled by Bell and Pirtle, 1966.

2.2 Opler points out that such applications "may require considerable queuing of elements and the development of complex priority assignment and recognition schemes. This too produces new problems for both language and processor designers." (1966, p. 197).

2.3 A provocative comment with respect to flexible system design to meet varying client requirements is that of Greenberger: "The average user should not have to carry water to the faucet

in his own buckets, one at a time. The system should provide a continuous supply for him, with the hot, cold, and lemonade taps all within easy reach." (Greenberger, 1965, p. 34.)

See also Orchard-Hays, who comments: "The value of an efficient and flexible system is not that it saves a little machine time. Rather, its value is that it allows us to make mistakes cheaply and thus to gain more experience in shorter time and with less expenditure." (Orchard-Hays, 1965, p. 242.)

2.4 In particular, it should be recognized as predicted by Bauer that if, as of 1965, "on-line computing probably represents 1 per cent of the total computer activity in the country today. It will probably represent 50 per cent in five years." (p. 14).

2.4a "We must realize always that a penalty or a price is extracted for each increment of increased human efficiency; more computer time, more complex computers, greater input/output equipment, and increased console costs. The tradeoffs undoubtedly favor ever increasing on-line capability. However, no system design should occur without recognition of the prices demanded." (Bauer, 1965, p. 18).

2.5 "In a cooperative input transcription project, the basic transcription into machinable form for each report or document will include: authors' names, title, all identifying numbers and dates, name of issuing agency (at all divisional levels), any other identifying text, and an abstract of the contents of the document. Additional material which may optionally be added is pagination, text excerpts, descriptors, classification signs, or other index terms added at the point of transcription. . . .

"The transcription—instead of being done at each and every retrieval collection over the country—is done once and for all either at the source of the document or at one of a group of cooperating retrieval systems, with the machinable transcription in the form of cards, or perforated or magnetic tapes, being prepared and then circulated to all of the cooperators." (Mooers, 1959, pp. 20, 21).

"This plan offers several advantages to the retrieval center and cooperating institutions in addition to the speed of manuscript transmission via paper tape. First, this machine-readable record of the bibliography or portions thereof, will be made available to cooperating documentation units, and the possibility of reciprocal exchange exists. Also the preparation of edited machine-readable bibliographic entries is done once, never having to be repeated . . .

"The first large scale implementation on an international basis of the 'tape-typewriter plan' for cooperation between documentation centers, has been initiated between Italy and the United States. This particular application of the plan entails the transmittal of entries in an international serial current bibliography from the . . . FAO . . . headquarters, Rome to the Aquatic Sciences Information Retrieval Center (ASIRC) at the University of Rhode Island . . ." (Scient. Info. Notes **5**, 3, 1 (1963).)

"Another use of the reactive typewriter will be for preparing documents, reports and books. Not only will it be of assistance in making editorial changes and revision, but, when the text is completed, the reactive typewriter can be used to specify the final page make-up for printing, the type styles and sizes, and location of illustrations. From this specification, the reckoning machine will prepare a tape record to be used to control one of the new high-speed photo-composing machines for producing a high quality, typographically perfect final product. On the other hand, if only an editorial proof copy is desired, and quality of printing is not important, a high speed printer at the site of the reckoning machine will be used. These can print out some ten to twenty pages a minute. Mail or messenger service will ordinarily be fast enough to bring the results back to the user." (Mooers, 1965, p. 34.)

2.6 "The CTSS environment consists of approximately 250 users whose individual load on the system varies from nearly zero up to the equivalent of several hours of IBM 7094 time per month." (Scherr, 1965, p. 5).

2.7 ". . . The possibility of retrieval via an on-line dialogue. This approach has been under study by Kessler of the Massachusetts Institute of Technology, implemented in a small experimental design by Salton of Harvard, and is realized in the current Lockheed working system." (Drew et al., 1966, p. 3).

With respect to the application at Harvard, Rocchio reports that in order "to establish the value of real time interaction in mechanized document retrieval, and to investigate the effects of the various types of feedback which might be provided to the user, three basic facilities are required:

(1) a time-sharing system to effect on-line man-machine communication at a reasonable cost, such as the Compatible Time-Sharing System (CTSS) available at M.I.T. for the IBM 7094.
(2) a flexible set of document retrieval programs which are capable of incorporating information received from the user and of providing alternative retrieval operations;
(3) a communication-oriented executive routine designed to provide the man-program interaction and to control the scheduling of the various processing options in a manner compatible with the time-sharing system." (Rocchio, 1964, pp. XII–1, XII–2).

2.8 "In its present configuration, a user may sit at an electric typewriter, scan a stated range of literature and perform a search based on key words, keyword in context, citation index, bibliographic coupling, author, location and various combinations of these. The response is printed back on the same typewriter within seconds of the request. The interaction between the user and the system is free of intermediaries and is accomplished by means of a language very close to natural English." (Kessler, 1964, p. 1).

In addition, provision is made for maintenance of personal files for individual users:

"Instead of specifying what to find the program is directed to read a file called SMITH. . . . [which] may contain a list of authors, citations, and/or key words that Mr. Smith is particularly interested in . . . He may change it from time to time . . . This provides the user with a combined author index, citation index, KWIC and share search tailored to his individual needs." (Kessler, 1964, p. 21).

"Night Letter. In this program a stated literature range is to be searched. When a reference is found to a prepared list of papers, a letter is printed, addressed to the author of the cited paper telling him the journal, volume, page, title, author, and location of the paper that cited him." (Kessler, 1964, p. 19).

"A set of programs has been developed under the general name of SHARE. In this process, we name an article and ask that other articles be found that share some element with it. One may ask for author, word, location, or citation share." Further, "it is possible to create 'standing orders' that will be fulfilled at some slack time when the computer is free from immediate demands, usually late at night." (p. 17)

2.9 "TEXTIR (*TEXT* *I*ndexing and *R*etrieval) is a set of programs which were developed as part of a joint experimental project undertaken by the Los Angeles Police Department (LAPD) and System Development Corporation (SDC) in the computer retrieval of crime data in natural English language . . . The basic capabilities of TEXTIR include automatic indexing of every substantive word in machine-readable reports or documents, and retrieving preselected portions of these indexed reports in response to natural English language queries." (Farrell, 1965, p. 7). This system based upon the AN/FSQ–32 computer, conventional Model 33 teletypes, CRT display consoles, and light pen input facilities is also discussed by Schwartz et al. (1965). It is in operation nine hours a day for more than 30 users simultaneously. (Commun. ACM 8, 253 (April 1965).)

"The entire document . . . is read into the computer . . . All the words in the document are ordered alphabetically and duplications are eliminated to produce a Document Word File . . . The Document Word File is compared against the Word Screen File; all the little words and obsolete words are deleted . . . all the topic tags are retained and the relative address of each topic tag is entered . . . all the equivalence words are retained along with the associated topic tag and its relative address . . .

"At this point in the processing, the Document Word File consists of topic tags, their associated relative addresses in the Word Screen File, equivalence words, and the words of the document which are not in the Word Screen File. This latter set of unidentified words is set aside and pointed out as an output to the personnel of the central facility . . . (who) can check this list and determine whether any new topic tags, equivalence words, or little words need to be created. The topic tags in the Document Word File are ordered alphabetically, duplicate topic tags are deleted, one is added to the document frequency tally in the Word Screen File associated with each topic tag . . ., the request frequency tally and the document frequency tally are copied from the Word Screen File and entered along with each topic tag in the Document Word File . . .

"The Document Word File now consists of the equivalence words and the topic tags in the document, along with the request frequency and document frequency tallies . . . (and, the) assigned document number. This version of the Document Word File is used to update the Topic Tag Index File and also to create the automatic abstract of the document . . ." (Geddes et al., 1963, pp. 179–180).

2.10 Borko gives the following account: "Now you see the listed subcategories, and again you use the light pen to make your selection. In this manner you narrow your field and reduce the number of documents to be searched. You may then ask to see the documents in the subcategory that you have selected. On the scope you will see the author and title of the books which have been classified into that category. You may now browse through the file and make your selection. On request, you will be given the appropriate call number and you may ask for a microfilm copy. The microfilm image could be transmitted to you on the display console or . . . mailed to you."

Some further details of the SDC system are as follows:

"The BOLD data base generator builds tables of structured information from a Hollerith prestored magnetic tape. The tables are designed with extensive linking between entries referenced by identical key words or phrases to permit rapid retrieval. The data base that is presently being used was obtained from the Defense Documentation Center and consists of abstracts of approximately 6000 documents. . . ."

"The function of the data base generator subsystem is to process prestored data tapes and to establish the linking between the index terms and other descriptive attributes such as authors, titles, contract numbers, etc. The data tables produced by the data base generator are used by the retrieval program. . . ."

"The display and retrieval subsystem is designed to search the data base that has been structured by the data base generator program and to retrieve and display the requested information. . . .

"The retrieval program has the following characterostocs:

(a) Allows, and therefore monitors, many users who are interrogating the same data base but who are doing simultaneous, independent, real-time retrieval.

(b) Permits the user to interrogate the dictionary and find out whether a word has been used as an index term—and how often—and whether there are synonyms or related terms.
(c) Allows the user to formulate his requests in natural language with very few computer-oriented restrictions.
(d) Displays retrieved information on a teletype or CRT console.
(e) Copies the retrieved information on a magnetic tape for off-line listing. . . ."

"The BOLD inquiry station consists of a teletypewriter and cathode ray-tube display unit. The user interacts with the system and requests information by typing on the teletypewriter. He may also make certain requests by using the light pen and the display scope . . .

". . . [A] display appears that indicates the 32 divisions or main subject categories into which the data are divided. If the user wishes a further breakdown, he may use his light pen to flash a division. By doing so, he is requesting more information about that category and receives a display of the subdivisions. The display also supplies the number of entries in the category. If he chooses to browse through the items in this category, he may do so . . . The display he would receive is the first abstract in that category.

"Should the user decide to keep a permanent copy of the display for future reference . . . the information is transferred from the scope to the teletype." (Borko and Barnaugh, 1966, pp. 6–7, 8–10, 12, 21).

2.11 "The system which is now working at LMSC depends upon two other operating Lockheed systems. The first, MATICO (Machine-Aided Technical Information Center Operations) supplies the machine-readable data base. The second, ADA (Automatic Data Acquisition), supplies the on-line computer and its time-sharing monitor . . .

"The types of information used as descriptors are: (a) personal author, (b) all significant title words, (c) corporate author, (d) all subject headings (an average of three per report), (e) contract number (f) original report number, (g) secondary report number, and (h) date of publication." (Drew et al., 1966, p. 4).

2.12 "It is possible to further restrict a retrieved set of citations by year of announcement, announcement media . . . or announcement series number. . . .

"By displaying the alphabetically near terms, the user is able to see not only if and to what extent the term he entered has been used as an index term, but also any spelling or ending variations on the term which have been used." (Summit, 1967, pp. 53–54).

2.13 "The current operating environment of the DIALOG system is an IBM 360/30 (32 thousand bytes of core) together with two 2311 disk packs (7.5 million bytes each) for programs and intermediate storage, a 2321 Data Cell (415 million bytes) mass storage device for the reference corpus, a 1443 offline printer, and a 2260 display/1053 printer input/output terminal. The reference file consists of some 300,000 NASA announced citations." (Summit, 1967, p. 52.)

2.14 "In another application, called Project CIDS—for chemical information data system—the computer will list all chemical compounds that fit the specifications in a user's inquiry, giving formulas, physical and chemical properties, and all known chemical and commercial names. If the inquiry is too general, the satellite computer will indicate this before the search is started . . .

"An information-retrieval system called Project Vector is being developed, with which an uninformed person can use an inexpensive terminal to gain access to a vast library of information that would otherwise not be available to him . . .

"Other applications include research in the locating of legal precedents and experiments in man-machine interaction in game-playing." (Carr and Prywes, 1965, p. 89).

2.15 "Under a [NASA] contract with the Bunker-Ramo Corporation, consoles will be installed in users' immediate working areas, hooked-up by telephone lines with a central computer-search system . . . The user 'types' topical terms, authors' names, or similar identifying data which he believes are pertinent to his query. Within seconds, corresponding citations begin to appear on the viewing screen . . . If the user likes what he sees, the pressing of other buttons will record his interests so that the cited documents may be sent to him. If not, he can modify his search until relevant citations do appear." (Sci. Info. Notes 8, 12, 13 (1966).)

"One of the concerns of Project Intrex is to conduct a series of experiments to determine how the traditional library catalog can be effectively augmented and combined with on-line computer operation to provide users with a more powerful, comprehensive, and useful guide to library resources. Present plans call for augmenting the traditional catalog in scope, depth, and search means. For example, the augmented catalog will contain entries for reports and individual journal articles as well as the traditional entries for books. Furthermore, in addition to the title and author of each item, such things as the bibliography, an abstract, key words, and key phrases of each item will be included as part of its catalog entry. A user will be able to conduct searches on nearly any combination of the data contained in a catalog entry. Present plans also call for providing alphanumeric communication between user and computer by means of a high-speed, flexible display console." (Haring, 1968, p. 35).

2.16 "SAFARI is an on-line system for text processing designed to be used by a group of information analysts for building their own personal files. The system allows an analyst to scan through documents displayed on a CRT and to select relevent facts which then are processed linguistically and stored in the computer in the form of

366-108 O - 70 - 4

logical content representations. To locate information, the analyst can initiate a search through the stored representations to identify those with relevant content. When an item of interest is found, the original text from which it was derived can be recovered. On-line editing capabilities allow the analyst to take all or any parts of the recovered texts, add commentary and interpretation, and generate reports about their content." (Walker, 1967, p. 144).

2.16a "It is felt by many that an on-line computer system, which allows a user to converse directly with the computer in his quest for relevant document citations, can provide a more effective environment for information retrieval than is possible with off-line systems. The on-line systems permits information retrieval to be a highly individualized process with respect to time of occurrence, question at hand, and characteristics of user." (Summit, 1967, p. 51).

2.16b "We believe that this approach to data analyses—a computer-mediated interplay between the investigator and his data—holds promise of a more effective inductive analysis than either man or algorithm could produce alone." (Press and Rogers, 1967, p. 39).

"One of the more promising areas of computer use involves the coupling of a man to a computer system for real-time problem solving where the procedure for solution of the problem is either unknown or involves complex tasks such as pattern recognition, that can best be performed by humans." (Brown, 1965, p. 82)

"Use of the graphical input-output console allows the designer to pause and study his design at all stages in its process without unnecessarily tying up the computer. Furthermore, he can make modifications at any time and be appraised within seconds of the effects of each change." (Hamilton and Weiss, 1965, p. 3).

2.17 "It seems vitally important to press on with the development of multiple-console computer systems, particularly in organizations in which creative potential users abound." (Licklider, 1965, pp, 68–69.)

2.18 "Another area in which responsive data processing offers recognized economy and convenience to the scientist or engineer is ease of learning, ease of use, and ease of making corrections . . . A properly designed system can function as a teaching machine, indicating mistakes or misunderstandings as they occur." (Adams, 1965, p. 484.)

2.19 ". . . The cooperation of man and machine takes on the character of a dynamic bilateral process of mutual training whereby the man, having at first adapted himself to the confined language of the machine, then step by step raises it to his level, partly by concrete clarifications and explanations of general rules, but equally by the confirmation of generalizations successfully made by the machine itself." (Yershóv, 1965, p. 323.)

2.19a Glauthier (1967) provides a review of the relatively brief history of computer time-sharing systems. He covers such relatively early developments as Strachey's 1959 paper, the M.I.T.-Lincoln Laboratory-SAGE developments, the Speed Tally system, airlines reservation systems, stock exchange quotation services, the CTSS (*C*ompatible *T*ime *S*haring *S*ystem) at M.I.T., the Bolt, Beranek and Newman system, and others. We also note the following:

"The most complex system to date is the INTIPS system at the United States Air Force Rome Air Development Center. It combines multiprogramming, multicomputing, remote personal consoles, remote graphical input-output devices, and remote conventional I/O devices. It is a lineal descendant of the original RW 400 Polymorphic Computer developed by the Ramo-Woodridge Corporation." (Wagner and Granholm, 1965, p. 286).

2.20 ". . . An algorithm is used to determine dynamically how much of the system's resources a task ought to be allowed to consume. If this threshold level is exceeded, the task is forced to stop and wait while other tasks have a chance; in other words, *forced* multiprogramming of sorts. (This has been generally termed as *time-slicing*)." (Comfort, 1965, p. 620.)

"A time-sharing system slices time in such a way that each user gets a small amount of attention on some periodic basis." (Ware, 1967, p. 288.)

2.21 "The scheduling algorithm is that set of rules, or more strictly its embodiment in a program, which govern the frequency with which each user is serviced and the length of time each program is permitted to run before it is interrupted . . . The correct form for a scheduling algorithm is one of the most hotly discussed aspects of a time-sharing system, and a great deal of experimental work will still have to be done before the question can be settled." (Samuel, 1965, pp. 12–13).

"Real-time programs may require considerable queuing of elements and the development of complex priority assignment and recognition schemes. This too produces new problems for both language and processor designers." (Opler, 1966, p. 197).

One obvious implication is that: "Responsive time-sharing . . . needs more collaboration between software and hardware designers than has been evinced thus far." (Adams, 1965, p. 488).

2.21c "Some attention must be paid . . . to the methods by which the policy decision, once arrived at, is to be enforced. It is desirable that these methods should allow as much flexibility as possible in the choice of quantum and should not add significantly to the cost of scheduling." (Lampson, 1968, p. 355).

See also the following:

"The Manager program provides control for a general-purpose time-sharing system to make its hardware and software usage more efficient in servicing many users. In substituting computer operator management control devices for the built-in algorithms of other systems, the program bridges the gap between on-line user demands and programmed system user control, and provides a human element in

system management. As time-sharing systems expand and improve, new demands on such systems can be expected. The incorporation of more programmed solutions into time-sharing systems might seem to be the best approach to allocating the system resources, but the cost of this approach may be very high in terms of maintenance and flexibility. However, on-line computer operator management tools cannot be expected to augment software needs for long, as systems with hundreds of users begin to pose more severe demands on this human element. Eventually, all large time-sharing systems will include elaborate management programs, with a clerical staff that manages the systems. Because the human element will continue for a long time to be a part of time-sharing system management, more elaborate display devices will eventually be required, to assist the operator, and to give him as much timely information as possible. On the other hand, the need for users to be aware of certain system resources should be less of a requirement. When procedural problems do occur, however, they should be able to communicate by voice from their teletype stations with personnel who can give assistance to them. The Manager program is merely a beginning in the control and management of time-sharing system use." (Linde and Chaney, 1966, pp. 157–158).

2.22 ". . . We may expect future application programs to be built with a mode control permitting the user to operate the program in either a batch or conversational mode." (O'Sullivan, 1967, p. 172).

"The time-sharing system at the University of California at Santa Barbara uses an interesting variation of the above methods. A user is required to state whether his job is interactive (short, frequent requests) or batch (longer, usually single requests). Time is divided into fixed length segments such that during the first half of each segment, the interactive jobs are served in a round robin fashion until their half-segment is exhausted (or until their collective requests are satisfied). The remainder of the segment is then used to service (to completion, if possible) as many of the batch jobs as possible. During the first half-segment, some interactive jobs will drop from the queue after one quantum of service (e.g., those requiring the acceptance of a single button-push), etc; thus in this system, there is a benefit in declaring the nature of your job in an honest way, since in the case where there is only one batch job and many interactive jobs, the batch job receives better service if that user declares himself as being in the batch mode." (Coffman and Kleinrock, 1968, p. 16).

"Time-shared systems are tending to find it convenient to run short jobs to completion and to interleave stacked production jobs into long pauses in online operations as background jobs." (Sackman, 1968, p. 2).

2.23 "By whatever means, it seems clear that priorities and reservation systems will be required to assure certain classes of users appropriate quality of service. . . . Reservation mechanisms typically arise where a facility (or right) cannot be shared (pre-emptive rights cannot) and where the facility users wish to plan ahead with a high degree of certainty that their plans will materialize." (Brown et al., 1967, pp. 213–214).

2.23a "Although there are many systems today that provide time-shared access to a computer, little is known of precisely how such machines are used. This was especially apparent at the beginning of the JOSS development. Substantial effort was therefore made to provide a measuring or instrumenting capability within the system not only to record use of the system as a whole but also to record characteristics of use for individual users of the system." (Bryan, 1967, p. 769).

"The JOHNNIAC Open-Shop System (JOSS) is an experimental, on-line, time-shared computing system which has been in daily use by staff members of The RAND Corporation since January 1964. It was designed to give the individual scientist or engineer an easy, direct way of solving his small numerical problems without a large investment in learning to use an operating system, a compiler, and debugging tools, or in explaining his problems to a professional computer programmer and in checking the latter's results. The ease and directness of JOSS is attributable to an interpretative routine in the JOHNNIAC computer which responds quickly to instructions expressed in a simple language and transmitted over telephone lines from convenient remote electric-typewriter consoles. An evaluation of the system has shown that in spite of severe constraints on speed and size of program, and the use of an aging machine of the vacuum-tube era, JOSS provides a valuable service for computational needs which cannot be satisfied by conventional, closed-shop practice." (Shaw, 1964, p. 455).

"JOSS* is a special-purpose computing system designed to provide users with a substantial and highly interactive computational capability. The first JOSS system, developed for the JOHNNIAC computer machine by J. C. Shaw, was operational in early 1963. Work on an expanded system utilizing a modern PDP–6 computer began in 1964, and the system became operational in February 1966." (Bryan, 1967, p. 769).

2.24 Examples in current systems include the following: "Priorities . . . can be assigned on a dynamic basis depending on how long the program has been in the system, or how much time remains before the deadline for results." (Bauer, 1965, p. 23.)

"In defining the scheduling algorithm one must specify:

(a) the sequence in which active users are to receive service and the variation in this sequence as load conditions change,

*JOSS is the trademark and service mark of the RAND Corporation for its computer program and services using that program.

(b) the amount of time (under all circumstances) each user or type of user is to receive." (Schwartz et al., 1965, p. 19.)

"Scheduling within SHARER is done on a round-robin basis, with the central processor being allocated to each program in central memory at least once every half second." (Harrison and Schwartz, 1967, p. 662).

"The management of the queue would be according to the following principles:

1. Processes are entered into the queue by program forks and the completion of *i/o* functions.
2. A process is taken from the queue and placed in execution whenever a processing unit becomes free.
3. A processing unit becomes free when it encounters a quit or *i/o* function procedure step, or the process has exceeded its allotted time." (Dennis and Glaser, 1965, p. 9.)

"If a user remains in the same queue for more than 60 seconds without being run, he is moved to the end of the next higher priority queue." (Scherr, 1965, pp. 119–120.)

"A user may be allotted time in any or all shifts. If he consumes his allotment on a given shift, the system automatically logs him out, and he must wait until the beginning of a shift in which he has resources remaining before he is permitted to log in again." (Mills and Van Vleck, 1966, p. 5.)

"Priorities are assigned user's programs on the basis of length and previous running time. In order to keep efficiency up, longer programs are given slightly less priority because they require longer swapping time." (Scherr, 1965, p. 119.)

"A user is pre-empted, that is, another user will be swapped in, if the current user is no longer the first user in the queues, *and* he has run as long as the new first user will run . . ." (Scherr, 1965, p. 120.)

"A variation on the first-come, first-served system is called round-robin priority. When a program's time is up, the computer samples all incoming lines in a prescribed order until it finds a request to run . . .

"A more complex priority system has been proposed whereby a computer could whittle away at large problems in its 'spare time', when it is not busy with simpler, high-priority services. Several different levels of service could be offered, at different speeds and prices." (Riley, 1965, p. 74.)

"The scheduling algorithm currently operational in the Q–32 system utilizes three priority queues, each circling in simple round-robin fashion, with queue position dependent upon the amount of CPU time required for a request." (Schwartz and Weissman, 1967, p. 265.)

At Case Institute of Technology, "a revised selection algorithm is under development which will select jobs according to a complicated nonlinear function of both estimated running time and time spent waiting in the input queue." (Lynch, 1966, p. 122.)

"Each program on the library is to have one or more queuing codes incorporated within it to control the minimum service level of that program during busy running periods. The resulting priority chain will thus be a combination of first-come, first-served modified by minimum levels of serviceability associated with each program." (Baruch, 1967, p. 148).

"Some experience is now available about the behaviour of scheduling algorithms. It is found that the simplest algorithm—a straightforward round-robin in which each object program when loaded receives the same quantum of time—is not satisfactory, and that it is necessary to cater separately for small brief jobs and for longer jobs. This can be done by having a separate queue on to which jobs are transferred when it appears that they are taking rather a long time on the regular queue; once on the second queue, they receive larger quanta of time when they are activated, but have to wait longer between activations. Corbató implemented in CTSS a more elaborate system in which jobs which do not terminate, or which reach an input or output wait, during a period of activation receive double the quantum of time during the next period, but have to wait twice as long for it. The quantum of time received when a program is first activated, or when it is reactivated after a wait, is determined according to the amount of core space occupied, larger jobs receiving a larger quantum." (Wilkes, 1967, p. 2).

"The scheduling algorithm operates roughly as follows: Each user request is assigned an initial priority which depends only on the size of the program that must be run. The highest priority is assigned to the smallest programs. The highest priority programs are allowed to run for a maximum of 4 seconds before being interrupted, whereas lower priority programs are allowed to run for longer intervals which are multiples of 4 seconds. The lower the priority, the longer is the allowed interval. If a program run is not completed within the allowed interval, the program is transferred from core memory to drum (the state of the machine being automatically preserved), and its priority is reduced by 1 unit." (Fano, 1964, p. 16.)

"Jobs for the slowest peripherals are given priority until a reasonable amount of output for the device is waiting in the output buffer, then the scheduler moves on to the next slowest peripheral. We have found that the optimum choice for this 'reasonable amount of output' keeps each peripheral in maximum use if the demand exists." (Morris et al., 1967, p. 69.)

"In ATLAS, all jobs are fed into the system as soon as they appear. A scheduling program selects those jobs having input/output characteristics which will tend to put as many of the computer components into motion as is possible." (Collila, 1966, p. 49).

"A queuing structure more sophisticated than the simple round robin approach should be implemented. Distinction among the factors causing tasks to give up control of the processor provides a reason-

able basis for the queue organization. Servicing of queues to put interactive tasks back in control of the processor as soon as possible distinctly improves response times at no cost to processor utilization." (Oppenheimer and Weizer, 1968, p. 320).

"The design of the priority and quantum assignment algorithms must take the upleasant possibility [of a ready process never being run] into account. This might be done by restricting the frequency with which a process may enter the ready list with high priority. Another alternative is to restrict the length of time it may run at high priority, although this one may be subverted by the fixed overhead imposed by the need to swap in the memory for the process. Still a third approach is to increase the priority of processes which have been waiting for a long time at low levels." (Lampson, 1968, p. 355).

"Second priority is given to users who have given JOSS output-limited tasks which have been set aside until the typewriters have nearly caught up. Third priority is given to users with unfinished tasks, on which JOSS works for two seconds apiece in round-robin fashion. A user's priority changes dynamically according to this discipline, which successfully exploits the parallel processing of the communication system. Under a typical load, JOSS responds to simple requests in a fraction of a second and rarely in as long as three seconds. Users who are skilled in typing can maintain impressive rates of interaction with JOSS." (Shaw, 1964, p. 459).

2.25 "When service is effected according to an a priori scheduling algorithm, the communication network is used to gather user requests arising at *unscheduled* times and to distribute results after servicing ordered queues of requests. . . . When service is effected according to a dynamic scheduling algorithm, processing time quanta, which may be variable, are assigned to each request." (Estrin and Kleinrock, 1967, p. 85.)

2.26 "To exploit the increase of capacity gained by distributing, the system must provide for queuing. The queue depth permissible should be at least as great as the number of components over which the function is distributed." (Amdahl, 1965, p. 38.)

"An unconditional guarantee of access (given the facility is operational) can only be provided by a priority system if preemptive priorities are issued to no more users than can be served simultaneously. Otherwise, the guarantee will fail on occurrence of a peak load." (Brown et al., 1967, p. 214).

2.27 It is noted that, in typical scheduling systems, client-processing use is of the order of two to four seconds but that during this interval several hundred thousand processing instructions may be executed; that the client's own response-time requirements (either to receive a textual message and/or display or to type-in a response) generally require at least three seconds, and that allowing a quantum time of ten seconds is almost equivalent to allowing any client's problem to run to completion. (See Scherr, 1965, p. 11, 68.)

2.28 "The response time of the system to a line of input from the user is an important parameter of a time-shared system. In fact, it is one of the few, well-defined, measurable performance parameters available. This response time determines the basic rate at which the user can operate." (Scherr, 1965, p. 19.)

"The apparent response time is a subjective evaluation of system performance made by a console operator in a man-machine system. Extensive human-factors tests are required to ensure that an acceptable real response time is, in fact, an acceptable apparent response time." (Aron, 1967, p. 53.)

". . . The ratio of response time to processor time per interaction will be substituted for response time. It turns out that this ratio is a more stable measure of CTSS performance. The variation of this ratio as a function of the average number of interacting users is a measure of how well the system responds to a change in its load." (Scherr, 1965, p. 56.)

"The most important performance aspect of any man-machine system is the quantity of results obtained (in terms of 'significant' problems solved) per unit time. At this time, such a quantity is unmeasurable." (Scherr, 1965, p. 96.)

"While it is recognized that response time and costs are not sufficient conditions for the evaluation of an information system, they are necessary conditions." (Blunt, 1965, p. 10.)

2.29 "Even a very small inter-job overhead may be a tremendous fraction of the total system capacity. Even a substantial overhead during the job, e.g., multiprogramming can result in a gain in total system capacity." (Perry, 1965, p. 246.)

"If mean response time is of primary interest, simple mathematical models can be constructed having good generality and yielding accurate results." (Scherr, 1965, p. 109.)

"Response time is a function of equipment speed; efficiency of the man-machine interface, operating programs and procedures and the communications capability within the system." (Blunt, 1965, p. 6.)

2.30 "When two or more data units are waiting at the same event for servicing, it is often possible to expedite processing by selecting a data unit under some other criterion than first-come-first-serve. For example, selection of the data unit with the least expected servicing time may both reduce overall response time and equipment/personnel idle time . . . Another criterion of data unit selection is to process the data units in a sequence such as to minimize computer idle time or to maximize utility of the central processor." (Blunt, 1965, p. 64.)

"While different queue unloading strategies can produce different effects in processing, not all of these strategies are likely to be easily applied in the real world. Casual comparison of two data units may not effectively reveal which element will process faster in a given event, or which processing sequence will better contribute to effective utilization of the central processor." (Blunt, 1965, p. 64.)

2.31 "The effects of users getting 'into phase' with each other . . . This phenomenon occurs when many users require service at the same time and is self-perpetuating. That is, as more and more users begin waiting, service for the individual user is reduced, and there is time for more users to reach the point where they require service. Thus, users tend to fall into step with each other; many working at the same time, many thinking at the same time." (Scherr, 1965, p. 25.)

2.31a "Multi-programming adds a good deal to the complexity of the design of a scheduling algorithm. When the running program is halted, it is no longer a simple question of what program is to be loaded to take its place. There is first a decision to be taken as to whether a new program should be loaded into core at all, and if so which program is to be dumped in order to make room for it. If no new program is to be loaded it must be decided which program already in core shall be activated. The taking of these various decisions is complicated by the fact that programs vary very much in size, and that it is of prime importance to make the utilization of available memory space as nearly optimum as possible." (Wilkes, 1967, p. 2).

"Because short response time is vital for an effective multi-console system, an effort must be made to predict for any system design how queueing will increase the obtainable response time. One way to do this is to assume the 'worst case' situation, in which a command encounters maximum possible queueing delays in being processed, and then design for an acceptable worst case response time. This approach is satisfactory perhaps while such systems are largely experimental. But the obvious drawback in relying solely on 'worst case' predictions is that the system is over-designed, and the true capacity of the system is underestimated. This can be serious economically when people seek more widespread access to use of these systems. So a study of response time which takes into account its statistical aspects is desirable both for a prediction of true system capacity, and to point out which system components limit the capability so that remedial action can be taken if needed." (Fife and Rosenberg, 1964, p. H1–1).

2.32 "The first large system to be used like a public utility is the IBM Quiktran System. It shares its consoles not among individuals within the same organization, but on a service bureau basis to anyone in the geographical area." (Wagner and Granholm, 1965, p. 286).

"An information processing utility consists of *processing units* and directly addressable *main memory* in which procedure information is interpreted as sequences of operations on data, a system of *terminal devices* through which users may communicate with procedures operating for them, and *mass memory* where information is held when not required for immediate reference." (Dennis and Glaser, 1965, p. 5).

"Another conception of time-sharing is that it is akin to a community utility capable of providing computer power to each customer. This notion was introduced in a lecture in 1961 by Professor John McCarthy. Very little concerning this concept appeared in the 1965 literature; an exception being Fano's paper, which describes the MAC system as 'an experimental computer utility which, since November 1963, has been serving a small but varied segment of the MIT community.' Another exception is the paper of Dennis & Glaser, which outlines some concepts of computer system organization that have arisen from the evolution of an information processing utility as envisioned by Project MAC . . ." (Davis, 1966, p. 225).

"The use of a separate processor for all interactive data I/O for TSS has given SDC the ability to interface a large variety of devices with TSS. These include teletypes, special keyboards and typewriters, lightpens for displays, special pushbuttons, high-speed data lines for computer-to-computer communications, automatic dial-up units, as well as the graphic tablet display console. To provide quick response time to the user of the GTD console, the PDP–1 performs a significant amount of preprocessing on the raw data. A project is currently underway to study the trade-offs of allowing the slower PDP–1 or the faster Q–32 to perform the required user functions. Although the user cannot directly modify the PDP–1 executive interactively, a system programmer can modify it to meet new user requirements." (Gallenson, 1967, p. 690).

2.33 "Computer-directed procedures are an important aspect of on-line computing and are little understood or appreciated. For example, they allow a complex query to be asked of a machine under the control of another machine and with the assistance of a third machine." (Bauer, 1965, p. 18).

"Remote batch processing involves a computer at the user terminal, rather than simply a typewriter alone. This low-cost computer is used to prepare a local batch of programs for direct transmission to the large-scale central computer." (Aron, 1967, p. 63).

O'Sullivan (1967) describes an interface computer used in support of terminal network, to provide code translations, bit formatting, error checking procedures.

2.34 ". . . Special processors should be designed to allocate and relocate users' areas in memories possibly in parallel with the main computation." (Lock, 1965, p. 471).

"The foregoing operations are usually *delegated*. That is, provision is usually made for a control unit, not a part of the central processor, which has the function of finding the desired item or location in storage, and of monitoring reading or writing. Because of this, the program is not held up by resort to the large storage, at least to the extent that the data is not needed forthwith." (Dumey, 1965, p. 257).

"Future time-sharing supervisors will run on computer systems having many processors, and many active memory modules, flexibly interconnected . . . They will provide for the dynamic allocation of space . . ." (Greenberger, 1965, p. 36).

2.34a For example: "Cooperative communication programs in the control and central computers supervise any interchanges between the console and the central facility." (Ninke, 1965, p. 842).

It is to be noted further that "these [operating] systems encompass all the language processors and commonly used utility routines in addition to controlling all components of the equipment, servicing all traps and interrupts and accounting—in general running the show . . . Such a system is designed to bring to bear a number of powerful and standard programs on relatively simple computing tasks, and to keep them moving through the queue". (Orchard-Hays, 1965, p. 238).

2.35 "Today's fastest machine cannot be loaded down and will be idle most of the time unless it is coupled to a large number of high speed channels and peripheral units . . . In order to distribute input-output requests in a balanced flow, it must also be controlled by a complex monitor that chooses wisely among the jobs in its job queue." (Clippinger, 1965, p. 207).

"Dynamic memory allocation is a necessary requirement for an engineering computer system capable of solving different problems with different data size requirements. . . .

"Dynamic memory allocation does involve additional machine cycles, but it also eliminates many bookkeeping requirements and the packing of information that are necessary without its use." (Roos, 1965, p. 426, 432).

"Memory mapping and dynamic storage relocation under control of the supervisor will make it possible to call library subroutines by name and to effect linkages to subroutines at the time they are called." (Licklider, 1965, p. 182).

"Storage allocation strategies must be fully integrated with the overall strategies for allocating and scheduling the use of computer system resources." (Randell and Kuehner, 1968, p. 303). Further,

"The choice of a suitable storage allocation system is strongly dependent on the characteristics of the various storage levels, and their interconnections, provided by the computer system on which it is implemented." (Randell and Kuehner, 1968, p. 303).

2.36 "At the point in time when one user's program is stopped and another's resumed, the status of the former must be saved and that of the latter restored. This process is called 'swapping'." (Scherr, 1965, p. 1).

"In addition to the transmission of the actual programs, each swap is accompanied by the dumping and loading (with the drum) of the processor status and disk file status of the outgoing and incoming programs. This transmission consists of approximately 500 words in each direction." (Scherr, 1965, p. 36).

"It is now becoming possible to overlap the execution of one program with the swapping of two or more programs so that little or no time is lost." (Samuel, 1965, p. 9).

2.37 "With each computation there is associated a set of information to which it requires a high density (in time) of effective reference. The membership of this working set of information varies dynamically during the course of the computation." (Dennis and Van Horn, 1965, p. 11).

"A variable sized data structure is handled by making it a distinct segment and allocating more or fewer blocks to it as the structure changes in size." (Dennis and Glaser, 1965, p. 8).

"Two effects occur: first, each operating burst is lengthened by the amount of additional program execution time required to select and reactivate the program and to preserve it upon termination. Secondly, the idling delays are lengthened by the amount necessary to complete the execution of one of the other time-shared programs." (Brown, 1965, p. 82).

2.38 "Reduction in swap time would result if only those parts of an object program and its environment actually involved in the current operation were loaded into main memory. Thus, many large programs could be modularized operationally to improve their performance under time-sharing." (Schwartz et al, 1965, p. 19).

2.38a "The purpose of paging is to relieve the programmer of the need to manage physical store. To the programmer a paged store is indistinguishable from an unpaged store *of the same size.*" (Laski, 1968, p. 35, *underlining* supplied).

2.38 "The choice of page size is clearly critical. Both the decreasing cost of core and the importance of minimizing supervisor overheads point to a fairly large page. At the present time, I would regard 4K as the minimum to be considered and would, perhaps, choose 8K. I am aware that smaller pages have often been advocated. The situation is complicated by the fact that the supervisor requires to use small blocks of memory (say 64 words) for input and output buffering, and there is a case for making some special hardware provision to enable it to do this efficiently." (Wilkes, 1967, p. 5).

2.38c "One of the most important problems in the construction of a dynamic storage allocation scheme is that of recovering storage space which is no longer being used by the program. The mechanics of detecting the existence of such 'garbage' have been adequately described (Newell et al., 1964; McCarthy, 1960; Collins, 1960; Schorr and Waite, 1965). In the case where the elements of storage required by the program are of variable size (Comfort, 1964; Ross, 1961; Knowlton, 1965) it may happen that an element of a certain size is needed and, although sufficient free space is available, no

free element which is large enough can be found. For example, suppose that 20,000 words of memory were allotted as a storage area to contain one- and two-word elements. If the first, third, . . ., 19999th words were all occupied by one-word elements, it would not be possible to obtain a two-word element even though 10,000 words were free. What should be done in this case is to 'compact' the store by moving all one-word elements to one end, leaving a single 10,000 word block of free space." (Haddon and Waite, 1967, p. 162.)

"A 'free storage list' of linked cells is the basis of most dynamic storage allocation schemes. Cells are generally removed from this list as they are needed by the processes of the language . . . Cells may be returned under program control, automatically as they are abandoned, or periodically by 'garbage collection'." (Raphael, 1966, p. 70).

2.38d "Even if an accurate ordering of core pages based upon frequency and recency of use could be inexpensively maintained, the value of that ordering for determining what core pages to free is questionable. The problem with the ordering is that a page chosen to be freed may be assigned to a task which has been between time slices (and therefore not referencing the page), but is just beginning a new time slice in which it will attempt to reference the page. One would like to order the core pages based upon the time at which they will next be referenced and release those with the longest projected inactive time (PIT) first. Although the system does not have such a projection on each core page, there is information in the system concerning the PIT of each task. Since a non-sharable virtual memory page belonging to a task can be referenced only when the task is in a time slice, a chain of tasks ordered with respect to the PIT of each task can serve as a partial ordering of the core pages which are allocated to non-sharable virtual memory pages. Then when a request is made to release core pages to the system, core assigned to the task at the top of this core release chain can be freed. We now consider the problem of defining a task ordering to serve as a basis for such a core release procedure." (Fikes et al., 1968, p. 13).

2.39 ". . . The importance of some of the well-known European contributions to the computer arts, for example, the page-turning procedures proposed with the original design of the Atlas, or the multi-processing algorithm included in the Gamma–60 . . ." (Salton, 1967, p. 203).

"In Atlas the instruction format permits the programmer to address directly 2048 blocks each of 512 words. Of these 2048 block addresses the most significant 256 are reserved for the use of the supervisor and are *sacred*, i.e., any attempt by a user program to access these reserved addresses is prevented." (Morris et al., 1967, p. 69).

"For each page of core store there is a use digit which is set when the page is accessed. All use digits are scanned and reset at regular intervals by the central executive and a pattern of use is established. The selection of the page to be transferred to the drum is made with respect to this pattern of use." (Morris et al., 1967, p. 69).

"In several recent computer systems, mechanisms (usually part-hardware, part-software) have been provided to give name contiguity without the necessity for a complete address contiguity. This is done by providing a mapping function in the path between the specification of a name by a program and the accession by absolute address of the corresponding location. The mapping is usually based on the use of a group of the most significant bits of the name. A set of separate blocks of locations, whose absolute addresses are contiguous, can then be made to correspond to a single set of contiguous names . . . The first example of such a system was the Ferranti ATLAS computer." (Randell and Kuehner, 1968, pp. 299–300).

"This was also the first use of demand paging as a fetch strategy, storage being allocated in units of 512 words. The replacement strategy, which is used to ensure that one page frame is kept vacant, ready for the next page demand, is based on a 'learning program'. The learning program makes use of information which records the length of time since the page in each page frame has been accessed and the previous duration of inactivity for that page. It attempts to find a page which appears to be no longer in use. If all the pages are in current use it tries to choose the one which, if the recent pattern of use is maintained, will be the last to be required." (Randell and Kuehner, 1968, p. 303).

2.40 Thus, for example, in the design of the IBM 360/67, "there are four main characteristics of a system that has dynamic address translation. The total program need not be in memory when any part of it is being executed; those parts that are in memory may be in noncontiguous, nonsequential pages; the parts may be left in memory after the quantum of time is used up, unless it is necessary to swap pages of another program into their places; and if all this happens, when the original program is restored for another quantum it may go into a different area of memory the second time around." (Iverson and Yee, 1965, p. 81).

"Division into pages is performed with both hardware and software. The time-sharing supervisory program sets up software tables in memory, containing entries that define the starting points of the pages for every task that the program must control." (Iverson and Yee, 1965, p. 82).

2.41 "This paging procedure introduces another important concept: virtual memory . . . The programmer is limited only by the addressing capabilities of the machine; he has a machine which has as much memory as it can address. In the Model 67, this virtual memory is as large as 2^{24}—more than 16 million—bytes." (Iverson and Yee, 1965, p. 82).

"... Users appear to have an insatiable appetite for store and we consider large scale 'one level store' techniques to be vital." (Morris et al., 1967, p. 74).

"Dynamic memory allocation is a necessary requirement for an engineering computer system capable of solving different problems with different data requirements . . . The result of dynamic memory allocation is that the size of a problem that can be solved is virtually unlimited since secondary storage becomes a logical extension of primary storage." (Roos, 1965, p. 426).

"... Provide the user with a large machine-independent virtual memory, thus placing the responsibility for the management of physical storage with the system software. By this means the user is provided with an address space large enough to eliminate the need for complicated buffering and overlay techniques. Users, therefore, are relieved of the burden of preplanning the transfer of information between storage levels, and user programs become independent of the nature of the various storage devices in the system." (Daley and Dennis, 1968, p. 306).

"One important aspect in the efficient use of hierarchical storage that should be emphasized is the need for development of machine organization and software techniques that make the entire internal and on-line auxiliary storage appear as a single uniform storage to the user." (Hobbs, 1966, p. 41).

"A very important problem remains to be solved, however, and that is how to provide efficient access to this mass storage. Various schemes for organizing mass memory elements have been proposed, with storage arranged into levels by size and speed and with hardware for automatic transfer among levels as required. Efforts have begun to make the entire memory appear as one logical unit to the system user rather than as a primary and secondary memory with separate addressing mechanisms." (Pyke, 1967, p. 162.)

2.41a "The choice of a placement strategy should be influenced by several factors. These include the relative importance of minimizing storage fragmentation, the frequency of storage allocation requests, the average size of allocation unit, and the number of different allocation units." (Randell and Kuehner, 1968, p. 302).

"When it is necessary to make room in working storage for some new information, a replacement strategy is used to determine which informational units should be overlayed. The strategy should seek to avoid the overlaying of information which may be required again in the near future. Program and information structure, conveyed perhaps by segmenting, or recent history of usage of information may guide the allocator toward this ideal." (Randell and Kuehner, 1968, p. 302).

"An additional complexity in fetch strategies arises when there are several levels of working storage, all directly accessible to the processor. In such circumstances there is the problem of whether a given item should be fetched to a higher storage level, since this will be worthwhile only if the item is going to be used frequently." (Randell and Kuehner, 1968, p. 302).

2.42 McGee (1965) provides the following definition: "Given a number of programs (each of one or more segments that have been partitioned into pages and stored in main memory), the function of a dynamic relocation technique may be stated as follows: For each reference (s, i) by program r to the ith word of segment s, determine if the reference is legitimate and, if so, translate the reference to the memory location of the referent. If the reference is not legitimate, signal a protection exception." (p. 196).

2.43 "The attack on the single store concept [as if there were] must be accounted a failure thus far. No executive or software system to the authors' knowledge has solved this problem in a generally acceptable manner." (Wagner and Granholm, 1965, p. 288).

2.44 "It will be necessary to develop techniques for transferring information on demand, and in anticipation of demand, from the slow, more voluminous levels of the hierarchy to the faster, more readily processible levels." (Licklider, 1965, p. 63).

Use of "WILL NEED" transfers and other techniques to manage storage hierarchies have been developed for Illiac II in order that this relatively small computer (8,000 words of core) can be run on time-sharing applications. (Fisher and Shepard, 1967, pp. 77–81).

2.45 "Dynamic allocation of data achieves the following:

1. Arrays are allocated space at execution time rather than at *compilation* time. They are only allocated the amount of space needed for the problem being solved. The size of the array (i.e., the amount of space used) may be changed at any time during program execution. If an array is not used during the execution of a particular problem, then no space will be allocated.
2. Arrays are *automatically* shifted between primary and secondary storage to optimize the use of primary memory."

"Dynamic memory allocation would extend to *programs* as well as data. Programs can then be brought into primary memory only when they are needed."

"The allocation of programs and data must be properly balanced so that the use of primary memory is optimized." (Roos, 1965, pp. 426–427).

2.46 Thus, "it cannot be stressed too strongly that the strategies of storage allocation must be fully integrated with the overall strategies for allocating and scheduling the computer system resources." (Randell and Kuehner, 1968, p. 301).

We note also the following: "The strategy of storage accessing by the central processor is one

of planning so that all needed data (and program segments) are available in the highest level storage unit at the time of accessing or with minimum delay." (Opler, 1965, p. 275).

"The case of variable units of allocation is in general more complex because of the additional possibilities of moving storage within working space in order to compact vacant spaces." (Randell and Kuehner, 1968, p. 302).

2.47 "The assignment of variable size data structures to a conventional memory is a formidable problem because the space of physical locations for information and the space for names of information coincide . . . If too few locations are assigned to a data structure, difficulty arises when additional locations are needed. Not only must physical memory be reassigned, but the addresses used to refer to them must be reassigned in name space." (Dennis and Glaser, 1965, p. 6).

2.48 "Multiple memory accessing becomes a burden when the total system responds to outside calls, because then the time scale or patience of the caller is the determinant." (Dumey, 1965, p. 259).

2.49 ". . . Special processors should be designed to allocate and relocate users' areas in memories possibly in parallel with the main computation." (Lock, 1965, p. 471).

2.50 "The various requirements of relocatability of programmes and data, indexing of addresses, allocation of storage space and protection of vital information, are all met at present by *ad hoc* provisions in the system design. Clearly they are all interrelated, and a unified approach to the design problem could perhaps meet them more economically." (Gill, 1965, p. 204).

"Dynamic storage allocation is achieved through changing the associations of blocks of physical main memory with pages of segments. Common reference to a data segment by several processes is possible simply through the use of the same segment name by both processes. It is natural to implement data lockout on a segment basis." (Dennis and Glaser, 1965, p. 8).

"If it is desired to protect the data object from destructive manipulation by an untrustworthy computation, routines with protected entry points . . . must be employed." (Dennis and Van Horn, 1965, p. 15).

2.51 "It is likely that multiprogramming systems of the future will adopt some form of grouped page storage allocation, where the group of pages allocated during a single storage allocation interrupt is determined either by the structure of processes or by the storage requirements during the previous activation of the process. . . .

"The problem of efficiently partitioning a problem into hyperpages may be thought of as a *clustering problem* in which individual pages are represented by vertices into clusters having high density of traffic within clusters and low density of traffic between clusters. However, it is not clear that significant clustering patterns could be established at a level at which clusters were significantly smaller than complete programs. Moreover, clustering patterns within programs are likely to vary with time, and is likely that a look-behind technique for paging of individual processes would be more effective than a 'static' clustering technique. . . .

"The information specifying the 'cluster' of most recently used pages is an important piece of information and could be used for page control if it were available. It is felt that storage of the set of virtual page addresses on termination of a process as part of an extended stateword, might be a worthwhile hardware extension. For example, if these virtual page addresses were available, then the loaded process could check for the presence of these pages and bring in any missing ones in parallel with the initial part of its computation." (Wegner, 1967, pp. 149–150).

2.51a "A basic allocation problem, 'core memory management', is that of deciding just which pages are to occupy main memory. The fundamental strategy advocated here—a compromise against a lot of expensive main memory—is to minimize *page traffic*. There are at least three reasons for this:

"(1) The more data traffic between the two levels of memory, the more the computational overhead will be deciding just what to move and where to move it.

"(2) Because the traverse time T is long compared to a memory cycle, too much data movement can result in congestion on the channel bridging the two memory levels.

"(3) Too much data traffic can result in serious interference with processor efficiency on account of auxiliary memory devices 'stealing' memory cycles." (Denning, 1968, p. 324).

2.52 "The 'page-turning' or 'look-behind' concepts can be employed at three levels in connection with segmentation. First, page turning may be employed within any segment so that only pertinent pages are kept in main memory. Second, the look-behind principle can be applied to the problem of deleting entire segments from core memory so that new information can be brought in. Finally, a look-behind technique can be used to avoid use of the page index except when reference is made to a new block of a segment." (Dennis and Glaser, 1965, p. 8).

2.53 "The concept of a page-turning memory—a scheme by which only pertinent blocks of information are kept in main memory while nonpertinent blocks are deleted through a suitable algorithm—is very useful for certain classes of procedures and data structures . . . (but) schemes that have been discussed to date do not allow for flexibility of application as they are not tied to a philosophy of program structure; that is, the selection of information to be deleted is independent of its function in the system." (Dennis and Glaser, 1965, p. 6).

". . . It is sometimes claimed that a further advantage of a paging system is that it entirely eliminates the problem of storage fragmentation. Rather, what is true is that paging just obscures the problem, since the fragmentation occurs within pages. It is only rarely that an allocation request will correspond exactly to the capacity of an integral number of page frames, and many page frames will be only partly used." (Randell and Kuehner, 1968, p. 301).

"It is difficult to assess with any certainty the benefits of a demand-paging strategy in a time-sharing system. Computer configuration, work load environment, and other system characteristics such as scheduling and priority schemes all strongly influence system performance; performance itself means different things to different people." (Fine et al., 1966, p. 11).

With respect to the studies by Fine et al, Smith remarks: "In a recent paper by Fine, Jackson, and McIssac, some relevant statistics on the dynamic behavior of a particular set of programs were reported . . . The authors concluded that there was considerable doubt about the worth of the page on demand strategy. Certainly any suggestion that it would be useful to multi-program a few pages from many programs in the high speed memory was negated by these statistics." (Smith, 1967, p. 636).

Smith himself states that: "The techniques of multiprogramming and paging have been proposed as means for efficiently adapting a computer system to an interactive type of load. The implementation of these techniques requires a considerable hardware investment for the handling of dynamic relocation and the best control policy remains to be determined." (Smith, 1967, p. 636).

2.53a This conclusion rests in particular upon findings that "the initial call rate for pages is extremely high; the first ten pages, on the average, were required within about 5.6 ms; in half of the cases where 20 or more pages were required, the first 20 pages were needed within about 7.0 ms." and that, in terms of the number of instructions executed between consecutive calls for new pages, "in nearly 59% of 1737 cases, less than 20 instructions were executed; in about 80% of the cases, less than 200 instructions. In only 2.3% of the cases, 10,000 or more instructions were executed between calls; these longer sequences occurred usually only after the program had accumulated a majority of the pages it required." (Fine et al., 1966, p. 6).

2.53b "Suitable systems programs are just now becoming available which permit time-shared mutiple console operation. Much more work remains to be done, however, in the optimization and refinement of these systems programs. Much also needs to be learned concerinig the optimum use of core storage for graphics time-sharing, establishing suitable priorities for the consoles, protection of one user's programs from disturbance by another user, and assurance that adequate secrecy will be provided to data when required." (Prince, 1966, p. 1705).

2.53c "Since the program under test is likely to be faulty, it is desirable to protect both the user's permanent objects, and any objects created by the PLS (programming language system) on his behalf from unintentional use or destruction by the procedure being debugged." (Dennis and Van Horn, 1965, p. 21).

2.54 "A number of users are testing procedures under development that are not free from errors. Program malfunctions induced by such errors must not interfere with correct execution of tasks proceeding concurrently for other users." (Dennis and Glaser, 1965, p. 9).

"Programs very likely to contain errors must be run but must not be permitted to interfere with the execution of other concurrent computations. Moreover, it is an extremely difficult task to determine when a program is completely free of errors. Thus, in a large operational computer system in which evolution of function is required, it is unlikely that the large amount of programming involved is at any time completely free from errors, and the possibility of system collapse through software failure is perpetually present. It is becoming clear that protection mechanisms are essential to any multiprogrammed computer system to reduce the chance of such failure producing catastrophic shutdown of a system." (Dennis, 1965, p. 590).

2.55 "While losses of users' programs and data have occurred, their frequency and seriousness have not discouraged users from entrusting their work to the system." (Fano, 1964, p. 18).

2.56 "Daily and weekly monitoring programs have been devised that test the integrity of the data. If any fault is detected it can be localized and repaired from any of the back up tapes that are kept for that purpose." (Kessler, 1964, p. 9).

2.57 "For *n* equal to the number of terminals currently connected, we can . . . (make) the time-sharing operation introspective—that is by having it gather statistics about itself. But we cannot use this device in general, unless we are willing to change *n* repeatedly. Even the most callous administrator would hesitate before subjecting his customers to that series of disruptions." (Greenberger, 1965, p. 35).

2.58 "The technological trend toward large random access memory suggests the retention of several users' programs in core simultaneously, hence mutual memory protection must be ensured." (Lock, 1965, p. 457).

"Each user, and each user's program, must be restricted so that he and it can never access (read, write, or execute) unauthorized portions of the high-speed store, or of the auxiliary store. This is necessary (1) for privacy reasons, (2) to prevent a defective program from damaging the supervisor or another user's program, and (3) to make the operation of a

defective program independent of the state of the rest of the store." (Samuel, 1965, p. 10).

2.59 "The [memory protection] capability must be dynamic and under flexible control of the executive program, since the allowed operating areas of the memory change on a millisecond basis." (Bauer, 1965, p. 23).

2.60 "Since a segment may be in several spheres of protection at once, we have a basic framework for allowing independent tasks to share access to procedures and data as appropriate. . . .

"The attachment registers will only contain segment names to which valid references may be made within the established sphere of protection, with an indication of the class of reference permitted." (Dennis and Glaser, 1965, p. 10).

"The complete memory protection solution demands that there be the option of read protection . . . Two important cases require it: The first case arises in debugging where a program reading beyond its bound has erratic behavior which in practice is indistinguishable from transient hardware failure. The second case is simply that of user privacy." (Corbató, System Requirements . . ., n.d., p. 6).

"Protection of a disk system requires that no user be able to modify the system, purposely or inadvertently, thus preserving the integrity of the software. Also, a user must not be able to gain access to, or modify any other user's program or data. Protection in tape systems is accomplished: (1) by making the tape units holding the system records inaccessible to the user, (2) by making the input and output streams one-way (e.g., the input file cannot be backspaced), and (3) by placing a mark in the input stream which only the system can cross. In order to accomplish this, rather elaborate schemes have been devised both in hardware and software to prevent the user from accomplishing certain input-output manipulations. For example, in some hardware unauthorized attempts at I/O manipulation will interrupt the computer." (Rosin, 1966, p. 242).

2.60a "Service disciplines may be classified according to the information on which they base priority decisions. Such a list would be open-ended; however, the sources of the information may be considered to fall in one of three not necessarily disjoint environments: (1) the job environment whereby the information consists of the intrinsic properties of the jobs (e.g., running time, input/output requirements, storage requirements, etc.), (2) the (virtual) computer system environment (e.g., dynamic priorities may be based on the state of the system as embodied in the number of jobs or requests waiting, storage space available, location of jobs waiting, etc.) and (3) the programmers' or users' environment in which management may assign priorities according to urgency, importance of individual programmers, etc." (Coffman and Kleinrock, 1968, p. 12).

2.60b "[In QUIKTRAN] extensive run-time diagnostics made possible by the interpretive mode are provided, and several unusual 'bookkeeping' features, similarly based on interpretation, are available, such as the AUDIT command, which generates information as to which portions of the program were never executed, which variables were never set, or set but never used, during a given execution of the program." (Evans and Darley, 1966, p. 43).

2.60c "For accounting purposes a multiprogramming operating system usually has to keep track of how much processor time is applied to each program and how much I/O channel time, by channel and device, is used by each program during its execution. Thus, the GECOS [General Comprehensive Operating System] II system keeps a running total by program of all processor, channel and device time used. These totals are updated for each period of processor use and for each I/O transaction. When a program terminates, all of its accumulated times are transmitted to an accounting file and the totals are zeroed for the next program." (Cantrell and Ellison, 1968, p. 214).

2.60d "PILOT is a programming system constructed in LISP . . . an interface between the user and his program, monitoring both the requests of the user and the operation of his program. Advising is the basic innovation in the model, and in the PILOT system. Advising consists of inserting new procedures at any or all of the entry or exit points to a particular procedure (or class of procedures)." (Teitelman, 1966, abstract p. 1, and p. 26).

2.60e "A time keeping device maintains a continuous log of computer operations assuming two essential record-keeping functions that up to now ordinarily have been handled by human beings. Known as the Time Monitor, it records, for each project, the overall time required to prepare, utilize, and unload a computer, the actual running time, the actual time for preparation and unloading, those periods during operation when the computer is inactive, the reasons for the stoppage. In addition to identifying operators, it can identify programs and programmers." (Computer Design **4**, No. 11, 25 (Nov. 1965).)

2.61 "Memory Activity—This . . . [shows] memory cell activity as a function of time. It presents a map of memory allocation and regional activity." (Coggan, 1967, p. 77.)

"Paging Activity—This presents a measure and map of page (memory block) use during specified time quanta. Separate displays for activity during compile, execute, etc., times may be desirable." (Coggan, 1967, p. 78.)

"Subroutine Activity—This function . . . aids in determining what subroutines should be included as part of the standard program vocabulary." (Coggan, 1967, p. 79.)

2.62 "Loop Factors—This display illustrates the total number of times around various loops defined by the program flowchart." (Coggan, 1967, p. 80.)

"Trap Activity—This is a measure of activity as a function of time for different trap types. It presents a map of program control interrupts." (Coggan, 1967, p. 79.)

2.63 "Queue Length—This presents a measure of the queue lengths for different classes of hardware, such as processors and memories, as a function of time." (Coggan, 1967, p. 82.)

"Work Profile—This is a display of the time breakdown for equipment usage and can yield information about particular equipment activity as a function of time, or serve as a comparison of equipment use over a fixed interval." (Coggan, 1967, p. 76.)

2.64 "Gibson Mix—This is a measure of frequency of instruction usage and serves as an aid in determining the types of instructions that should by hard-wired." (Coggan, 1967, p. 76.)

"Memory Profile—This gives a measure of the total number of memory cells used as a function of time and offers a direct comparison to the total number allocated. (Efficiency of use)." (Coggan, 1967, p. 77.)

"Branch Statistics—This is a measure of the branch probabilities for various branch groups. The display can help illustrate frequent and time consuming operations that might best be performed by more efficient program code." (Coggan, 1967, p. 81.)

"Program Overhead—This is a display of overhead time for different programs operating in a multiuser system." (Coggan, 1967, p. 83).

2.64a "The space-time product will be affected by the time taken to fetch pages, which will depend on the performance of the storage medium on which pages that cannot be held in working storage are kept. If page fetching is a slow process, a large part of the space-time product for a program may well be due to space occupied while the program is inactive awaiting further pages." (Randell and Kuehner, 1968, p. 302).

2.65 "Managers of a time-sharing operation will find themselves dealing more and more with the problems of how and when to interact with the system. One of the tools designed and implemented is the manager program. One part of this program displays all the users, their station number, size of program, work order number, priority number, and information regarding availability of space on disk, drums and tape drives. . . . The other feature displays all the programs that are on the disk: the program name, number of tracks, status (active or inactive), and date last used. Utilizing these programs, the monitor can get the information he needs to make tactical decisions." (Fiala, 1966, pp. 164–165).

2.66 "The development of the simulation program now provides a first-come-first-serve queue unloading strategy. Continuing effort, however, will provide for optional strategies, e.g., selecting the data unit with the shortest servicing time, consideration of what flow will minimize idle time at the central processor, etc." (Blunt, 1965, p. 15.)

2.66a "The logical units of information transfers carried out by recent supervisory systems represent a change from variable length program and data structures to the fixed length pages into which these programs and data are fitted. A number of important advantages accrue from this organization of information and have been described along with a corresponding control structure by Dennis and Arden, et al. A basic problem in this organizational approach has appeared in the form of poor object program operating behavior in a multiprogramming environment. In particular, the frequency of the page turning (transferring pages in and out of core memory) necessary to the execution of a program which, in general, is never wholly in core tends to degrade system performance by introducing as excessive amount of input/output interferences. . . .

"The two-page replacement algorithms whose performance is discussed here are as follows:

1. The Least Recently Used (LRU) Replacement Algorithm. Whenever a page of a given program must be turned out of core, this algorithm specifies that the page turned out must be the one which has been in disuse for the longest period of time since the beginning of program operation. This algorithm was selected because it is very similar to existing or proposed algorithms and admits of a fairly simple implementation.
2. The Belady Optimum Replacement (BOR) Algorithm. This algorithm is based on a prior knowledge of the entire sequence in which pages are used in the execution of a program. With this information and a specified maximum on the number of pages that can be held in core at one time, Belady has shown how to sequence the paging-in and paging-out operations in an optimum way, i.e., yielding minimum page turning. Because of its requirements the algorithm does not appear practical; however, it was selected in order to provide a means of comparing the performance of the various practical (and less efficient) algorithms with the best possible case. . . .

"The programs considered for analysis in this study represent rather different external characteristics. The programs selected include a SNOBOL compiler, a program for computing Fourier transforms, a WATFOR FORTRAN compiler, and a differential equation-solver. The last program is relatively small compared with the first three. The statistics for the larger programs have proved quite similar in nature and will be summarized by a detailed look at the behavior of the SNOBOL compiler which consisted of 15 instruction and 22 data pages, with a page size of 1024 words. . . .

"The principal observations from the data we have obtained are: (1) with the possible exception of carefully designed programs, the page turning incurred when programs are made to operate while substantially less than totally core-resident appears excessive in light of current or proposed paging

system designs; (2) a least-recently-used page replacement algorithm yields a performance within about 30 to 40 percent of that of the optimum page replacement sequence; and (3) for page residence confined primarily to small areas within the page size, performance is improved substantially more by increasing the number of pages held in core than by increasing the page size." (Coffman and Varian, 1968, pp. 471–472, 474).

2.66b "In either of the schemes described, or in any of their many variants, there is no difficulty about arranging that pages should be loaded only when they are required. There is, however, more difficulty in arriving at a satisfactory algorithm for deciding which page should be dumped when it is necessary to make room for an incoming page. One policy is to dump the page that has been longest resident in core, and another is to dump the page that has been longest resident in core without being accessed. More elaborate criteria, based on the past history of all pages in core, and taking account possibly of the fact that some programs are reacting with their consoles while others are not, may be constructed. Whatever is done, some supervisor overheads are incurred. Suggestions have been made for additions to the hardware which will reduce these overheads; perhaps the most useful is that there should be a bit in the hardware associated with each physical page which records whether that page has been accessed since the last time of resetting. Suggestions have also been made for some type of analogue timing circuit associated with each physical page which will enable the page longest resident to be identified very rapidly. It is not clear whether such a circuit could be designed so that it would record time only when the program owning the page was running." (Wilkes, 1967, p. 4).

2.66c For example: "Some problems have apparently been solved in an empirical or experimental fashion. For instance, we know of no theoretical studies on methods of allocation of processor time to various programs or on the optimization of information storage in memories with various hierarchy levels." (Pointel and Cohen, 1967, p. 46).

3. Storage, File Organization, and Associative Memory Requirements

3.1 "The management of secondary storage which has plagued programmers for many years should be handled automatically by the total software system. The designers of the software system for the ATLAS computer were pioneers in attacking this problem. We find the designers of most large modern software systems gingerly probing at the same problem." (Wagner and Granholm, 1965, p. 287).

3.2 "Data base storage will require medium capacity, random access, solid-state, on-line auxiliary storage; large capacity, low cost, on-line auxiliary storage; and very large capacity, very low cost, off-line auxiliary storage." (Hobbs, 1966, p. 41).

"Technology offers a broad variety of access and storage modes, so that less frequently used, or less valuable, records could be stored more cheaply at the cost of slower access." (Bohnert and Kochen, 1965, p. 157).

"We need to better understand the flow of data and develop design guidelines here, recognizing that the access 'gap' from electronic memory through electromechanical storage devices will cover a relative access speed differential of 10^3 to 10^5." (Hoagland, 1967, p. 258).

3.3 "In large time-sharing systems the means for organizing memory is of prime importance, and the next several years should bring a variety of solutions to this problem." (Pyke, 1967, p. 162).

". . . The problem of assigning data blocks and program segments *statically* to various types of storage units is replaced with the problem of moving such information *dynamically* through a hierarchically organized storage." (Opler, 1965, p. 275).

"The information conveyed by the fact of segmentation can be used by the system in making decisions as to the allocation of storage space and the movement of information between levels of a storage hierarchy." (Randell and Kuehner, 1968, p. 298).

"The dynamic nature of multiprogram on-line computation should have a strong influence on memory organization." (Lock, 1965, p. 471).

"If the extra memory which can be added can be overlapped and if there exists a hierarchy of memories of differing speeds then both the compilers and the operating system will have to concern themselves with making sure these features are used." (Clippinger, 1965, p. 211).

"Memory management—that is, having the right material in the right place at the right time—plays a central role and calls for a carefully thought-out strategy if the supervisory program is to handle this matter expeditiously and automatically." (David, 1966, p. 44).

3.4 ". . . The newer time-sharing systems contemplate a hierarchy of file storage, with 'percolation' algorithms replacing purging algorithms. Files will be in constant motion, some moving 'down' into higher-volume, slower-speed bulk store, while others move 'up' into lower-volume, higher-speed memory—all as a function of age and reference frequency." (Schwartz and Weissman. 1967, p. 267).

"In a multiple-access multi-programmed system, the use of paging gives a number of advantages. In the first place, when a fresh program comes to be loaded, it can go into any physical pages that can be made available, whether or not they are consecutive. Secondly, paging allows traffic in the channel between the drum and the core memory to be reduced, since a page of program need not be

loaded unless it is actually needed. The procedure is to load the first page of a program and send control to it. If, in due course, an attempt is made to access a word in another page, a supervisor trap occurs and the supervisor loads the required page. Since, in multiple-access working, programs are often loaded and run for short periods only (until they reach an input or output wait, or have exhausted their quantum of time), this advantage of paging is an important one. A further reduction in traffic can be obtained if, associated with each page register, there is a bit which is originally zero, and becomes set to one the first time the page is written into. The supervisor can then avoid writing back on to the disc pages which have not been altered during their residence in core. Memory lockout can be associated with pages if extra bits associated with the page registers are provided for the purpose." (Wilkes, 1967, p. 3).

3.4a "The reviewers believe that file-maintenance operations have not received adequate consideration in the design of file organizations. We noted that the use of indirect addressing of data could result in important savings for maintenance operations in indexed and multilist applications. It was also noted that an alternative design approach to accommodate maintenance requirements was to reserve space in storage for this purpose. It would be useful if quantitative performance studies were developed so that designers might know the circumstances under which one is more advantageous than the other." (Minker and Sable, 1967, pp. 150–151).

3.5 "The system design includes a hierarchical directory structure. Each item in a *directory* associates an alphanumeric name with a pointer to a *file*, an *input/output function*, an *entry point* giving access to some system service, or a directory giving further associations of names with pointers." (Quarterly Progress Report No. 80, Research Laboratory for Electronics, M.I.T, 257 (1966).)

3.5a "Early implementations of memory protection were aimed almost exclusively at providing the write protection function which is essential for guaranteeing that one program cannot destroy another. The multiusage environment adds further dimensions to memory protection requirements. Privacy considerations of privileged information (such as payroll data) require that portions of memory be protected from unauthorized reading as well as writing." (Mendelson and England, 1966, p. 62).

3.6 Barton comments: "Since multi-level storage is an economic necessity, its efficient utilization has long been a prime objective, though the difficulties appear formidable. In this regard, the machine designers have largely ignored the problem; extensive programmed control, very costly in terms of storage, is usually the consequence. It now appears that things can be done to alleviate this problem by providing adequate interrupt signals indicating states of tape, disc, and drum storage components and through use of simple adaptive schemes for handling information transfers between storage levels." (1963, p. 176).

3.7 "Unless an unexpected breakthrough reconciles fast random access with very large capacity, there will be a need for memories that effect various compromises between those desiderata." (Licklider, 1965, p. 63).

"The concept of storage hierarchies is very important in considering the use and capabilities of storage devices. There is no one ideal type of storage that fulfills all requirements while providing the maximum speed and capacity for the minimum cost." (Hobbs, 1966, p. 41).

3.7a "A MIS usually consists of two operational categories of programs; real-time and batch. The file system to support these processes must at least consider:

1. Security of information
2. Recovery of system operation after failure, and restoration of data when mutilated.
3. Key and Addressing schemes that will result in densely populated storage.
4. Need for additions and changes to the data base to meet changing requirements.
5. Performance requirements of all types of activity.
6. Reduction of wasted mass storage, consistent with performance requirements.
7. Coordination of the file system with the programming system." (Benner, 1967, p. 291).

3.8 "Hierarchical memory structures (with the levels set by the access-time characteristics) are common in mass storage systems to balance cost, capacity, and access time performance against applications requirements. . . .

"Economical mass-memory systems are the real key to extending the power of computers into many new applications." (Hoagland, 1965, p. 55).

"This 'main' memory size is related to the processing rate; the faster the arithmetic and logic units, the faster and larger the memory must be to keep the machine busy, or to enable it to solve problems without waiting for data." (Hoagland, 1965, p. 53).

3.9 "A stream is a combined allocation of several levels (presently core and disk) of storage, used as a single-level continuously addressable store." (Connors, 1966, p. 201).

3.10 "In my opinion, this problem of the minimal redundancy store must be considered as one of the long-range problems for information systems." (Mooers, 1959, p. 28).

An obvious practical requirement for consolidation or correlation of new input items with items previously stored is that of checking for duplicate entries in the file. Then, "in another . . . kind of situation, the flow of input documents will contain many facts or purported facts, and these must be compared with information in the files for veracity, consistency, novelty, or the like." (Mooers, 1959, p. 17).

In one illustrative experiment, it is reported that "in the case of a duplicate statement, only the set

identifier, R, is stored. The number of R's stored serves to enforce the validity of the corresponding statement." (Arnovick, 1965, p. 183).

3.10a Greenway and Russell point out that: "The final form in which information is presented to the user is a function of economics, required response time, and human factors. Thus, information presentation might range from a printed page to a high-speed sophisticated three-dimensional display device. The importance of human factors in information presentation is pointed out by the fact that display on a microfilm reader often appears very desirable from an economic and engineering standpoint, but meets with considerable resistance from users." (1965, p. 3).

3.10b "A viable file organization must be adequate from several points of view.

1. It must permit economical retrieval of items, by individual or by class.
2. It must permit economical modification of its items, by individual or by class.
3. It must be economically representable in one or more memory media of a computing system.
4. It must be adaptable to a range of computing environments, present and future." (Holt, 1966, p. 465).

3.10c "This paper describes the file handling system developed and being implemented as a part of INTIPS, (INTegrated Information Processing System) under the aegis of Rome Air Development Center. This file system addresses itself to the physical problem of the storage and retrieval of fixed length blocks and their organization into higher-order structures. It does not concern itself with the contents of these blocks. . . .

"The data base must be grossly expandable without reprogramming or redesign. Indices must be small and efficient while the data base is small but grow automatically with minimal decrease in efficiency as the data base increases to its projected maximum of 10^9 blocks. . . .

"The file structure is basically that of a tree. Blocks are grouped into files where a file consists of 1, 8, or 256 blocks. As will be seen in subsequent sections, by setting discrete sizes, one gains advantages in reduction of overhead when accessing related blocks and in simplification of the storage allocation problem. The choice of these three sizes was somewhat arbitrary but it was desired to have file sizes vary by approximately an order of magnitude. Files as well as blocks, may be symbolically named. No two blocks in the same file may have the same name but any given block name may be used in any number of distinct files. Every block is a member of one and only one file. . . .

"It can be readily seen that by allowing aggregates to consist of other aggregates as well as files, a structure can be developed which is many levels deep. These levels are called terraces. In addition, by permitting files and aggregates to be members of more than one aggregate the creation of lattice points* becomes possible. Thus a very rich structure can be created and manipulated with the file system. . . .

"As mentioned above, any aggregate may be an element of any other aggregate, indeed it may be an element of any number of aggregates. Similarly a file may be a member of any number of aggregates. Thus in both cases we have many records pointing to the same record. If such pointers were to be in the form of an address or anything else which was somewhat hardware oriented, each pointer would have to be changed whenever the record to which it pointed were moved. This would require reverse pointers in the record being pointed to so as to know which records require updating. One soon becomes enmeshed in an overwhelming maintenance job. Therefore, due to the very dynamic character of the secondary storage in INTIPS, it is necessary that inter-record references be symbolic. Aggregates, Files and Data Blocks can each be assigned a symbolic name by the user but these symbolic names do not readily serve the purpose of inter-record references because they are too long and also any given File can have many symbolic names. Therefore, another set of symbolic names was derived to be used for inter-record references. They are assigned by the file system solely for its own use and are called System Assigned Symbols (SAS's). Since these symbols are never exposed outside the file system they need not be binary representations of any legitimate alpha-numeric characters. Instead they are purely binary and therefore more compact." (Ver Hoef, 1966, pp. 75–77, 80).

3.11 "The activity method of file organization has an added appeal, because it provides the data for systematically purging the file of rarely used items." (Borko, 1965, p. 24).

"We make readily available those items which are most likely to be wanted and make relatively inaccessible those items which are least likely to be wanted." (Hayes, 1963, p. 287).

"Similarly, within the record different portions of the record have different activity rates. Frequently a record of 700 alpha-numeric characters in length will have a small portion, some 20 to 30 characters, that will get a major share of the activity. Some system designs use a "creamed" file of these 20 to 30 characters per record in a computer to answer 80 percent of the questions, with the other 20 percent handled by manual or microfilm files." (Tauber, 1966, p. 276).

3.12 "The system will reduce routine search time and conserve the more costly storage space by lessening the rapidity of access to data as it decreases in usefulness. Thus data on a particular individual who is incarcerated or has been dead for some time will be placed in storage with lower accessibility than data on active criminals." (Geddes et al., 1963, p. 24).

*A conventional tree structure allows any given node to subsume several nodes but it may only be subsumed by one node. If, on the other hand, such a node may be subsumed by two or more nodes, it is defined to be a lattice point.

"The optimal organization [of the data file] will depend on the primary functions of the system, and it may prove advantageous to have different parts of the file organized differently so that one part can respond efficiently to one kind of demand and another part to another kind." (Travis, 1963, p. 331).

"The file structure should exhibit the various levels at which data will be used, yet allow for the integration of all related data. Modified list-type structures designed for the needs of the particular system are worthy of much consideration for such files in order to provide the desired flexibility, growth, and cross-referencing." (Gurk and Minker, 1961, p. 270).

3.12a "Multiple entries for a file item expand the size of the file and require more duplicating and more infiling. The whole purpose, however, of a multiple-entry approach is to achieve an organization of the file so that all duplicates having to do with a particular code category may be brought together in one section of the file, then, when a search must be made, only a portion of the total file need be presented for the searching operation." (Kuipers et al., 1957, p. 258).

3.13 "Economic operation is feasible only if the predetermined pattern of the file organization corresponds to the environment." (Hayes, 1963, p. 268).

3.13a "More difficult problems arise when parallel use of files is being made and one job is terminated abnormally after only some of its tasks have been completed. What is the status of the updated file? The same question arises if a file is updated early in a job. Should the updated version of the file be made available to other jobs before the full job is completed? Conflicts of this type demand a great deal upon the necessity of the file being completely up-to-date and upon the various structures of the files. In general, the rule is that an up-dated file is not available until after its job is completed. If it should be available earlier, then that job should be broken into two other jobs so that at the end of the first job the file can be released. This makes the rules easier for users to understand and simplifies the restarting problem." (Gosden, 1964, p. E2.2–7).

3.14 "We will find random-access mass memory handling *images* as well as digital data by storing them in video and in digitized form . . ." (Hoagland, 1965, p. 58).

3.14a "Mass storage control logic is now beginning to extend to the functional ability to automatically arrange records within the hierarchy of memory/storage according to their activity, significantly improving access utilization." (Hoagland, 1967, p. 258).

"In applications involving the single-item search, the analysis performed by McCabe can be useful. He examines the possibilities of reordering a file based on moving the records for which a query has been made. Three methods of reordering the file are suggested: moving the retrieved record to the front of the file, exchanging positions with the record immediately before it in the file, and relocating a record only after a specific number of queries using either of the first two methods. Assuming the file must be searched serially for each query, he found that the two basic methods were equally as good in improving search efficiency and that using sampled queries merely slows the organization process." (Climenson, 1966, p. 112.)

3.14b "The performance region of several hundred million bytes of data with access in milliseconds is a key to many on-line 'data bank' type information systems and the appeal of such facilities spurs the rapid trend to direct access file-oriented systems." (Hoagland, 1967, p. 258).

3.15 The terms "associative memory" and "content-addressable" memories are generally used interchangably. Cheydleur, however, makes the following interesting distinction: "Content-addressability . . . can be described as the capability for locating items via their keywords (with the understanding that at various times any of the fields of an item suddenly may be subject to treatment as a key word) rather than locating via their actual memory addresses; basically this localization must be effected without benefit of any kind of serial sorting of files or subfiles either at the time of record or at the time of recall . . .

"The desirability of achieving an associativity capability, distinct from content-addressability, can be based on the need for coping with file requirements such as (1) multiple response, i.e., the correspondence of more than one item to the specification required; (2) inexact but close matching of 'most of the specifications'; and (3) rejection of items which have certain specified explicit descriptors." (Cheydleur, 1963, pp. 57–58).

Some other definitions are as follows: "An associative memory is a storage device that permits retrieval of a record stored within by referring to the contents or description rather than the relative address within the memory." (Prywes, 1965, p. 3).

"We have described here an iterative cell which can be used as a content addressable memory from which an entry may be retrieved by knowing part of its contents." (Gaines and Lee, 1965, p. 74).

"This paper describes a fixed memory consisting of one or more stacks of paper or plastic cards, each of which contains an interconnected array of printed or silk-screened film resistors. Each card is compatible with conventional key punches, and information is inserted by the punching of a pattern of holes, each of which breaks an appropriate electrical connection. All punched cards in a stack are cheaply and reliably interconnected using a new batch interconnection technique which resembles an injection molding process, using molten low-temperature solder. The circuit which results is a resistor matrix where the information stored is in the form of a connection pattern. The matrix may be operated as a content-addressable or associative memory, so that the entire array can be searched in parallel, and any word or words stored

366-108 O - 70 - 5

answering a given description can be retrieved in microseconds." (Lewin et al., 1965, p. 428).

"The information records in the associative memory are organized into lists. Each list can be visualized as a series of cells, each cell containing an information record, linked along a linear string which connects "associated" records. Each of the records may be of variable length and may have a number of associations, with a link to another record for each association. Each string represents an associative notion and has a corresponding name which is referred to in the following key. The branching lists make up what is known as a tree. The word tree figuratively describes the branching out of lists from the main chain of information which provides paths within the associative memory. Thus, the processes of storage and retrieval are regarded as establishing and following association links among the information records." (Prywes, 1966, pp. 1790–1791).

"An associative memory has two attributes: content-addressability and parallel-search capability." (Chu, 1965, p. 600).

3.16 "The content-addressable memory (CAM) was initially proposed by Slade as a cryogenic device." (Fuller, 1963, p. 2). See Slade and McMahon (1957).

3.17 "An early example of a parallel search memory was the 'multiple instantaneous response file' (MIRF), where the comparison function is built directly into the cells storing data items, permitting a given search specification to be reflected against all data cells simultaneously. Knowledge of the address of the qualifying data item is not needed. Address independence has also been achieved in list-processing systems, where search proceeds through a series of chained lists rather than in parallel. A short study of both approaches has been provided by Reich." (Climenson, 1966, p. 114.)

"Previous work in automatic data extraction, automatic indexing, and formatted file processing suggested that the techniques of content addressing and parallel processing afforded by an associative processor would offer significant advantages both in performance and in ease of programming for such applications." (Baker and Triest, 1966, p. 1–1).

3.18 "It is very unlikely that associative processors will be developed to an adequate state for widespread utilization in the foreseeable future." (Hobbs, 1966, p. 41).

3.18a "It is extremely unlikely that large fast associative stores will become practicable in the near future." (Scarrott, 1965, p. 137).

"In the past, associative or content addressable memories of any significant size have been impractical for widespread use. Relatively small associative memories have been built with various technologies, such as multiaperture ferrite cores, cryotrons, and various thin-film techniques. The logical flexibility of microelectronics now makes at least scratchpad-size associative memories practical." (Hudson, 1968, p. 42).

3.19 "The utility of content-addressable memories (CAM's) within a general purpose computing system is investigated . . . A simulation package is developed which allows simulation of CAM commands within job programs run on the IBM 7090 and derives tallies of execution times corresponding to a particular realization of a CAM system. The simulation package is used to evaluate algorithms for CAM commands and to evaluate the efficiency of CAM commands in a job program." (Fuller, 1963, abstract).

3.20 "Memory organization is the kernel of the Moore School's problem-solving facility . . . With the multilist technique information storage and retrieval are incorporated in the executive program and in a man-machine communication language called Multilang." (Carr and Prywes, 1965, p. 88).

"The functions of storage and retrieval of records are accomplished by the use of an *associative memory* which is simulated on an addressable memory by means of the MULTILIST technique. This technique . . . involves the use of an expanding *tree structure* as a dynamic index translating keys into addresses, and a *multi-association area* where the records themselves are stored." (Prywes, 1965, pp. 2–3).

"The Multilist system simulates a storage system that contains an associative memory as a substructure. From such a descriptive memory, a programmer can retrieve stored information by specifying a key—that is, by giving a description of the information desired, rather than its address." (Carr and Prywes, 1965, p. 88).

3.20a "An associative memory for large scale data processing can be implemented in a conventional addressable memory by simulation techniques." (Landauer, 1963, p. 863).

3.21 "One of Feldman's main points is that there is some evidence that large associative memories may be competitively simulated on conventional computers. His principal evidence is that the execution times are reasonably competitive, but he further argues that large associative memories can be simulated on immediately available hardware, and that the general-purpose machine has the ability to handle the multiple-hit problem and tree-structured data more readily. Another point is that "if much processing must be done outside the associative memory the saving in the time for the first access may be a negligible part of the total." (Climenson, 1966, p. 116).

3.22 "List organizations of memory are generally useful in problems for which:

1. Symbols having other than numeric significance are to be manipulated.
2. Dynamic storage allocation is desired since storage requirements cannot be determined in advance.
3. Orderings exist among symbols or among sets of symbols or both. Sets of symbols may have

many subsets. Subsets may belong to more than one set.

4. Orderings among symbols are restructured in the course of program execution.

Problems for which list storage has been used include theorem proving in geometry and logical calculus, chess playing, assembly line balancing, translation of natural and artificial languages, and information retrieval." (Fuller, 1963, p. 6).

3.23 "The choice of file structure within a random access device is dependent upon the problem. Multi-list file structures, chaining, address generation techniques, and dictionaries have all been found valuable." (Berul, 1964, pp. 10–17).

"A record is retained in file for each document. The record contains the code for each index term attributed to it. Next to the index term code is the address of another record which contains the same term code. A search for all records with a certain term code may be performed by 'threading' through the file from one random access address to another. . . .

"A further development of the Inverted List method has been developed at the AUERBACH Corporation. To reduce the amount of list manipulation, a technique is employed which selects the lists most liable to be critical in the search. Only these lists are manipulated, and the number of records ultimately retrieved from random access is greatly reduced." (Berul, 1964, pp. 8–24).

"The work of Lefkovitz et al., in developing an experimental system for a real-time chemical information system is of general interest because of its file structure features rather than its special interest for chemical retrieval. The work is being performed for the Army Chemical Information Data System (CIDS) effort. Except for some special features, such as chemical substructure searches and relational searches between entities, work in the general field of file structures is applicable to the chemical retrieval problem, and the specified chemical problems can be embedded within the larger framework. The file structure used in the CIDS project is a modified multilist file structure." (Minker and Sable, 1967, p. 140.)

"Modifications to the multilist file structure made by Lefkovitz et al., make it more of a combined inverted file, multilist structure. An automatic classification scheme is being developed to anticipate the types of questions and to place data in cells based upon their attributes and near-related data. The scheme is basically a data-storage allocation strategy for disc, which attempts to save accessing data on different disc head positionings. No experience exists on its usage. As the authors note, the efficiency of the system will depend highly upon whether the keys are indexed. For substructure searching, without other keys identifying the data, they found that a tape file compares favorably with a disc system. The authors believe that to be effective, the longest lists should encompass only a small part of the file. This work should be followed closely in future reviews. The reviewers believe that additional features, such as indirect addressing to names of records (as described previously with the registry number) and data descriptions, will be needed in the operational system." (Minker and Sable, 1967, p. 141).

3.24 "To achieve the full utilization of the memory space, any abandoned space must be 'recaptured' in order that it may be used subsequently for other purposes. The association memory . . . starts with all available space on a single long list, called the 'available space list'. Whenever space is required for building up a new list, this is obtained by using the words from the front of the available space list, and whenever information is erased and the words that held it become available for use elsewhere, these words are added to the front of the available space list. Thus, the fact that unused space is scattered all through the memory creates no difficulty in finding new space, for there is a single known word (the name of the available space list, ASL) that always contains the address of the next available word." (Hormann, 1960, pp. 14–15).

3.24a "Herner notes the two basic ways of organizing file material: the 'unit record' concept and the 'inverted file' concept. The advantages and disadvantages of each — in their pure form — were aptly described by Prentice: The unit record concept has the advantage of having all information in the record available for search at one time, resulting in high search precision. It has the basic disadvantage that all records in the file must be searched for every request. On the other hand, the inverted file search need only involve the pertinent part of the file, but it retrieves only record identifications; it must deal with unbalanced record posting densities, and the relationship between individual record terms is difficult to express and search." (Climenson, 1966, p. 109).

"Transience is a strong incentive to conventional term-on-item grouping. If the item has a short life, it is desirable to have terms grouped under items so that items and their terms can be deleted with ease from the store in one simple operation." (Wall, 1958, p. 172).

"Experience with the program has also shown that an inverted file of document numbers posted to indexing terms, the original scheme, is less suited to the total NASA information program than a linear file with complete document records placed on tape and searched in sequential order. With the linear arrangement, it is more feasible to divide the total file both chronologically and by subject area. Thus, to shorten the total time required to make any given search of the document store, only selected portions need be searched. The linear file is also most suited to a decentralized system in that the updating of searching files held by subcentral facilities might be done simply by distributing the new sections of data which are then easily added to the ends of existing files in the field.

A further result of experience with a decentralized system is that numerical codes for subject terms are troublesome, especially when the vocabulary is changing and evolving as fast as the aerospace vocabulary. Conversion of indexing data from codes to straight alphabetics was a natural solution for the NASA program; together with the linear file arrangement, it is expected to be effective in mid-1964." (Wente, 1965, p. 58).

"Variations in search logic can improve the efficiency of a file set with an inverted index. In the most common mode of usage, when the search specifies a Boolean combination of terms, the union and intersection operations can be carried out on the list of record locations retrieved from an inverted index. Another method that has been proposed by I. A. Warheit is to locate only one term of a request set in the inverted file, then search out the index records listed there. The full logic is applied only to the index records retrieved by this term. This method offers an advantage when the expected number of index records to be detail-searched is low, the number of comparisons to be made during the record search is also low, and the query terms are all intersected. The method works best if the least probable term can be selected from the request set and used as the only entry to the inverted file. This technique is called direct access searching .... Only one of the two query terms is looked up in the inverted index file. All index records containing that term are examined for presence of the other query term. This method reduces searches in the inverted file and eliminates cumbersome logical operations on the lists of document numbers retrieved from the inverted file. If a third table, an index of the inverted file, is used, it would be possible to include not only location of term records, but the number of index record references in each, and this could be used to select the single entry for the inverted file. On the other hand, maintaining and retrieving relative frequency of use data may use up all the gains otherwise provided." (Meadow, 1967, p. 239).

"It is even less desirable to invert a complete file in non-document-oriented files. The low search probability of most of the many fields in typical data records makes allocation of extra memory to speed the occasional search uneconomical. Consider what happens when the index file is sequenced on some more meaningful basis than accession number. We must certainly bear in mind that one result is a requirement to sort all incoming index records. Any sequence other than accession number must be sufficiently more efficient than access number order to overcome the penalty of sort time. Sorting on subject would often be desirable, but many indexing systems permit and encourage several subject terms per index. Sorting of index records by subject would then require each record to be replicated as many times as there are subject terms in the record. The inverted file concept avoids this potentially excessive use of memory by simply providing a cross-reference capability without replicating the full index record." (Meadow, 1967, p. 240).

"Combinations of the inverted file and unit record approach are replacing pure applications of either." (Climenson, 1966, p. 129).

"When data are stored on tape for a retrieval system, they are commonly organized by record name and other identifiers, followed by record descriptors. To speed retrieval, some designers provide an index that is searched first, followed by retrieval from the main file, which is sequenced on tape by citation number. However, Curtice shows that, for serial media, searching the main file is generally more efficient than searching the index. Thus, an index stored on tape may hinder rather than enhance retrieval time. Furthermore, the index must be maintained, thus making maintenance operations more complex. Curtice further notes that storing both the index and the main file on disc will lead to an advantage of the indexed approach not achieved for tape-stored data. Thus, we note again that the file organization, to be effective, must be matched against the physical storage medium....

"Experience on an actual system at the NASA Scientific and Technical Information Facility confirms Curtice's results. Brandhorst & Eckert present a brief historical review and a current updating of the NASA efforts as accomplished by Documentation Incorporated. They report that the straight linear-file search using tape is an improvement over the inverted-index search followed by a linear-file search. However, they intend to use the inverted-file approach for discs when their new computer is obtained." (Minker and Sable, 1967, p. 128).

"A linear file search approach was adopted for use in the system. An inverted file search economically demands permanent allocation of random access equipment, the expense of which precluded its use in the system. However, the Descriptive Terms Statistical Master File, the Satellite File which is used to produce the term postings report, is actually an inverted term file. Therefore, when inexpensive random access storage becomes available, the conversion expense to an inverted file random access search will be minimal. Also, unless hindsight indicates revision, the basic question statement method will be retained." (Ebersole, 1965, pp. 193–194).

"In an attempt to exploit the benefits of both an inverted file and unit-record concept and circumvent the disadvantage of each, Warheit has devised a so-called direct access search system where both kinds of files are used. The inverted file is used as an initial search filter on the basis of one or two coordinated search terms. The assumption is that, if there is a reasonably small number of document postings associated with the initial search terms, only a few records in the unit-record file must be searched in detail as the second step. The price

paid is storage redundancy. It should be noted that incomplete use of an inverted file is equivalent to exhaustive search of an inverted file where the terms have a many-to-one relation to the unit-record terms—that is, in systems where the terms are stored with some degree of imprecision (e.g., using one term in the inverted file for a range of record values or a code to represent several record terms). In both cases, a portion of the unit-record file must be examined to complete the selection task." (Climenson, 1966, p. 113).

3.24b For example, "Anderson et al., in work sponsored by the Army Research Office and conducted at the National Bureau of Standards, are experimenting with a linear file consisting of basic fixed-field information about the entry, plus links to satellite information files for a chemical retrieval system. As part of the same effort, Marron et al., developed programs for chemical structure or substructure searching based on the Hayward notation. Since no screening techniques, which serve to categorize the structures, are used in the implemented system, a linear search of the entire file is required. The authors recognize this limitation for an operational system." (Minker and Sable, 1967, p. 140).

3.25 "The rationale behind the inclusion of local scratchpad memories in the B 8500 computer module encompasses . . . the need for buffering of four-fetches of instructions and data in advance of their use, i.e., lookahead. Also important are its uses as storage for intermediate results, as an economical implementation for registers and counters, and for the extension of the push-down stack." (Gluck, 1965, p. 663).

"The storage queue contains words destined for storage and their absolute address. Since the storage function has the lowest priority in the communications unit, words are retained in this area until service time is available . . . [but] data being fetched are checked against the contents of the storage queue by the use of the associative memory . . . Fetching of data from a main memory location about to be updated by a word awaiting service in the storage queue would provide incorrect information to the program." (Gluck, 1965, p. 666).

3.25a "The power of the machine is achieved by using a small fast scratch pad memory for manipulating address fields . . ." (Wigington, 1963, p. 707).

3.26 "In the beginning, small associative memories will be provided as an adjunct to computers of conventional organization to permit fast table look-up, facilitate the performance of certain classes of information retrieval applications. Later, they may be employed to facilitate memory assignments, bus assignments and processor assignments. Still later, we may see the whole organization of the memory changed . . ." (Clippinger, 1965, pp. 208–209).

"Many systems applications of high-capacity, high-speed, random-access, read-only memories appear to stem from table lookup operations. In various forms, these applications include microprogramming, journal keeping, and arithmetic and logic manipulations." (Fleisher et al., 1965, p. 25).

"Lookahead designs, in which block transfers of instructions and data minimize memory accesses and transfers, have used scratchpad memories. . . .

"A major utilization [of scratchpads] has been the storage of intermediate arithmetic or logical results from a computational unit." (Gluck, 1965, p. 663).

"Many registers, formerly implemented with flip-flops, are now stored as words in scratchpad memories. Typically, such registers are utilized for index words, base registers, real-time clocks and similar relatively infrequent usages." (Gluck, 1965, p. 663).

"The incremental compilation achieved by indirectly addressing all operands through their reference entries suggests a small very-high-speed memory, functioning much like the index registers, to be used by all identifiers' reference entries." (Lock, 1965, p. 471).

3.27 "The key to the system is the presence of an Associative Memory Subsystem. The associative memories are used to provide dynamic control over processor assignments, to mechanize an automatic page turning scheme, and to provide important functions concerned with the execution of I/O commands." (Gunderson et al., 1966, abstract).

3.27a These authors comment: "The parallel search function of associative memories requires that comparison logic be provided at each memory word cell. The APP, by moderate additions to this logic, allows the contents of many cells, selected on the basis of their initial content, to be modified simultaneously through a 'multiwrite' operation." (Fuller and Bird, 1965, p. 105).

3.27b "The ILLINOIS Pattern Recognition Computer (ILLIAC III) . . . is designed for automatic scanning and analysis of massive amounts of relatively homogeneous visual data. In particular, the design is an outgrowth of studies at this Laboratory of a computer system capable of scanning, measuring, and analyzing in excess of 10^7 bubble-chamber negatives per year. . . .

"A Pattern Articulation Unit (PAU), whose duty is to perform local preprocessing on the digitized raster, such as track thinning, gap filling, line element recognition, etc. The logical design of the all-digital processor has been optimized for the idealization of the input image to a line drawing. Nodes representing end points, bends, points of intersection are labeled in parallel by appropriate programming. The abstract graph describing the interconnection of labeled nodes is then extracted as a list structure, which comprises the normal output of the processing unit." (McCormick, 1963, p. 791).

3.28 "The interrogation, which may consist of a number of descriptors, each containing many bits of information, causes an appropriate group of

solenoids to be driven . . . The solenoids interact simultaneously with all enclosed loops on all data planes, resulting in a simultaneous voltage on the output of each data plane that is the cross-correlation between the driven input solenoids and each individual data plane. The output of each plane is connected to its own detector-driver which tests the output in comparison with all the other data plane outputs to find that output containing the best correlation. Alternatively, the detector-driver can be set to test for some predetermined threshold." (Pick and Brick, 1963, p. 245).

4. Mass Storage Considerations

4.1 "Documents will probably be always with us because the material in them does not easily or economically lend itself to machine handling. Also, for some purposes (browsing, frequent reference) documents are more easily and more efficiently handled." (Brown et al., 1967, p. 64).

4.2 "One . . . factor is the likelihood of mutilation or theft of a given title. Until 1984, when every home will have its own microviewing device, no patron is as likely to remove reels as he is to remove issues. Every library can provide its own list of titles on which the razor and the scissor have wreaked frequent havoc; for such titles film would diminish the problem.

"A second element to be considered might be called the nature of the material—including both physical aspect and content. A weekly magazine of the size of Business Week or the New Yorker, in which the advertising matter cannot be removed will take up large amounts of shelf space in bound form. On the other hand an abstract journal is much more convenient to use when it is bound; one must turn from index in the back to abstract(s) in the middle, and it is far easier to do this with a printed volume than to reel and unreel continuously. A periodical with many illustrations, maps, and diagrams, especially if they are in color, will not be as suitable for microreproduction as one with text only. A periodical already in hard covers (Horizon) or one which can be purchased in hard cover form (American Academy of Political and Social Science Annals) can go directly from current shelves to stacks without being sent to the binder.

"A third element in the decision is the user of the material. Students at Staten Island, for the most part, never have seen a microfilm reader before coming to the college and are usually enthralled to use one. Not so their instructors. . . . represents the attitude of the professor; he prefers to take the periodical to his home or office rather than to be tied to the machine. The same is true of the serial cataloger. Good cataloging requires that each back volume be inspected; it is far easier to do so at one's desk where the ALA–LC rules are at hand than to have to go to some other area of the library where the film readers are. The division of location that microfilm requires may also be a hardship. If one has a long run of a periodical in bound form and then switches to microreproduction, the title is now shelved in two places. Even though the information about the switch is in the card catalog, the reader will often overlook it—especially in an open-stack library. In such a library it would be desirable to place a dummy after the last bound volume with some such statement as 'vol. ____ to date on microfilm.'

"For extended reading it is certainly true that print is much easier on the eyes than film, and the bound volume is more convenient for notetaking. In short, from the point of view of the user, the only advantage of film (and it is not an insubstantial advantage) is that the title is never absent at the binder or never on a processing shelf awaiting receipt of a missing issue so it can go to the binder.

"Fourth is the element of cost, and here a computer would be necessary to put into a proper formula all the factors involved. University Microfilms takes many of them into account in stating that to store a current periodical for a 30 year period by binding would cost $240.00, while to acquire and store the same periodical on film would cost $106.65. Ford suggests that even more can be saved by using a microfilm splicer to combine in one box on one reel three or four volumes of a periodical. He states that his library in this manner succeeded in reducing 72 boxes of film to 40 which saved 'almost 45 per cent of housing space plus the cost of splicing.' The clerical costs of preparing a volume for binding and checking the bound volume on its return no longer exist. The missing issue problem mentioned above is also a factor here. Frequently a missing issue is not noted until it is time to send the periodical to the binder. In many libraries this means that the title, sans missing issue, must be set aside until a replacement arrives, which means more storage space, more adjustment of records—in short, more cost. Further, when microreproduction is used, one can, in the case of some titles, sell the superseded issues to a second hand dealer and thus recoup part of the initial investment." (Peele, 1964, pp. 168–169).

4.2a In the *Annual Review of Information Science* for 1966, Van Dam and Michener comment as follows: "The improved accessibility of microform was a significant development in 1966. There were three aspects of this development. First, increasingly more microform was being produced and distributed, by the government as well as by manufacturers. To do the research for this chapter, for instance, some hundred microfiche were ordered from the Clearinghouse for Federal Scientific and Technical Information or through interlibrary loans, and were scanned on a $100 viewer. Most engineering drawings and other documentation must now

be supplied to NASA or to the Department of Defense in aperture card form. Thomas Publishing Company publishes product information in the form of microcatalogues. Aperture cards, particularly microfiche, were the most popular medium. Some minor revisions to the National Microfilm Association's microfiche standard specifications were published." (Van Dam and Michener, 1967, p. 201).

"In summary, then, there are three basic duplicating media—film, paper and tape. As indicated, magnetic tape requires facilities for interpretation, paper creates unmanageable storage problems, and flooding, a major problem, could destroy the records. Microfilm has a definite edge on both, as readers provide rapid interpretation, and flood damage can be controlled by a simple washing of the microfilm reels." (Butler, 1962, p. 63).

4.3 "Up-dating or additions and changes to the images in rolls of film used to be considered a contra-indication to the use of roll film in applications where up-dating is an important requirement. Because of the facilities afforded by magazines we can and do seriously propose roll microfilm today for some of these applications. And, moreover, such proposals are not at all necessarily based on film splicing or other non-dark methods of adding images to existing film. I refer, of course, to a more limited type of market, but my purpose is to illustrate some of the many new implications for the microfilm industry represented by the magazine concept and the methods and functions this concept facilitates." (Brunelle, 1962, p. 91.)

4.4 "The Microstrip System, offered by Recordak Corp., uses foot-long plastic holders for storage and retrieval of 12 in. strips of 16 mm microfilm. . . . File categories are distinguished by color coding on the end tab, which contains an index by content. The plastic strips are also indexed lengthwise to facilitate location of the desired image." (Bus. Automation **12,** No. 7, 47 (July 1965).)

"The Micro-Thin Film Jacket, marketed by the *Recordak Corp.*, accepts single microfilm images as well as strips, and permits the entire contents or any part to be copied by direct contact printing without removing the microfilm." (Systems **6,** No. 8, 6 (Aug. 1965).)

"It is clearly uneconomical to put all data into the computer. The data elements established so far in the design are essential. In addition, the documentalist knows that sometime, somewhere, someone will want and need additional corroborative information. Some type of microfilm appears most likely to meet the need for hard copy backup documentation, storage, and retrieval for all five QDRI RODATA files. At this point, we are concerned only with the *facility file*. Now, QDRI is not attempting to develop new techniques. Economy requirements have dictated use of a proven commercial system. About a year of search and discussion led to the conclusion that the VSMF cartridge or cassette system should satisfy QDRI RODATA needs. This is the same system that is in use by Chemical Abstracts and several library documentation operations using the Kodak Recordak or 3M Filmac reader printers. VSMF will make accessible to QDRI its own extensive file of commercial catalogs. Also the VSMF Vendor Selector questionnaire is identical in use and has major similarities in format to the Standard Form 129 and the DD Form 558–2 employed by the Army in establishment of R&D source data. The need for improved language in present Army and DOD forms is being met by the new R&D Category Index, coordinated by the Armed Services Procurement Regulations (ASPR) Committee with all of DOD and NASA." (Peirce and Shannon, 1967, p. 265.)

4.5 "We (Ford Motor Company Engineering) . . . changed over to 35 mm aperture cards . . . About 99.9% of our engineering drawings are now on aperture cards and are being distributed throughout the world on that basis." (R. H. De Rosa in "Systems Magazine's Third Annual Microfilm Seminar", 1965, 35).

Four new IBM microfilm products were introduced in 1965: "Key to the system is the microprocessing reusable aperture card which may be used to project information onto screens or to obtain paper copies. One of the products, a copicr/reproducer is a high volume machine that reproduces up to 2,100 cards an hour from the master micro-processing card. It enables the transfer of both punched holes and microfilm images from one punched card to another in a single operation." (Systems **6,** No. 6, 6 (June 1965).)

"A Texas architectural firm, Caudill Rowlett Scott, has developed a computerized microfilm file system enabling architects to stop 'reinventing the wheel'. By converting drawings and file material to IBM micro records, needed information can be retrieved and displayed, or reproduced, in a few minutes.

"In the past, CRS, like other large architectural firms, was constantly redesigning many common construction features such as ships ladders, flashings and curbings. The only alternative was the even more time consuming task of retrieving a particular drawing from the company's file of completed projects (bins containing all records pertaining to the completed project)—located in a distant warehouse. Since there is no statute of limitations on the responsibility of architects in Texas, the firm retains its files permanently. In addition to the time consumed, the usual results were frustrating failure.

"CRS's system employs both aperture cards and microfiche. Aperture cards are standard sized punch cards with a film frame mounted in a window on the card. The CRS microfiche are sheets of microfilm containing up to 90 images. Projected data, reduced to microfilm, will be readily available in an area adjacent to the computer room. If the architect wants to study the drawing, he drops the aperture card into a viewer. If he wants a hard copy, one can be produced in thirty seconds for him to study at his desk.

"Under its developing program, CRS also is analyzing all of its design functions, coding them and entering the data into an IBM 1130 computer. When completed, the computer will contain references to projects by design elements. An architect seeking to learn how a particular problem was solved in the past will cite the factor and the 1130 will list the projects containing that particular element." (Computers and Automation **16**, No. 10, 54 (Oct. 1967).)

4.6 "Currently, the 4 by 6 inch microfiche has been standardized and popularized by both government and industry. Two fundamental system requirements are filled by the microfiche unit record. First, it fits the human hand well, a mandatory requirement since the carrier must operate in manual as well as automatic systems. Second, it fits the information packages well, and therefore it will provide a least-cost file dissemination tool. This is achieved because the microfiche is usually relatively full. Thus, using microfiche, the user can obtain the lowest cost per page of any comparative method in publishing application." (Tauber, 1966, p. 280).

"Microfiche makes the duplicating library concept possible. In this concept the basic library is a file of microfiche. The user receives a duplicate microfiche, either negative or positive, made while he waits. Other optional outputs will be made available such as selectively producing hardcopy on a reader-printer or completely producing hardcopy through the use of a step-and-repeat enlarger." (Tauber, 1966, p. 281).

"Indexing acquisitions on tape, however, is only a part of processing. In establishing an operating philosophy for handling of materials, NASA was bound by the need for timeliness and the need to give individual service in providing the documents themselves. The best solution seemed to be microfiche. A single processing results in a micromaster from which any number of production copies can be obtained. The production copies are readable as is, with readily available equipment, and if the user wants hardcopy, a copy can be blown back from the microfiche and handed to him. We also considered the sheer bulk of files, the cost of handling and mailing tons of paper annually, and the vast storage space our NASA Centers and other service points would need." (Day, 1965, p. 130).

4.7 "Reductions greater than 35X have to have highly specialized associated storage and retrieval hardware unless these high reductions are being used to compress records for archival storage and thus not in high activity files. Perhaps we could consider any image reduced more than 35X as an 'ultra-microimage'." (Howerton, 1962, p. 23).

"The computer-controlled Magnavox 'Magnavue' and the IBM 'Cypress' 1350 photoimage retrieval system are both in the $1,000,000 range and therefore are for special high-priority operations only." (Van Dam and Michener, 1967, p. 202).

"Even if the system will be used under conditions such that successive regeneration of document images is not a limiting factor, there is a problem in that with increasing reduction ratio the film transport mechanisms in cameras, readers, and printers become extremely complicated. The greater the number of images stored within a given area of film, the more difficult is the problem of indexing, locating, and accurately registering any single one of them. Eventually a point is reached at which the cost and complexity of the image-registration mechanism discourage the use of higher reduction ratios." (RADC Summary of the State-of-the-Art, 1967, p. 16).

"Special systems based on document reduction ratios of 60 : 1 (Kodak Minicard), 140 : 1 (AVCO Corporation), and 200 : 1 (National Cash Register Company) have been successfully used for high-density document storage, but they require special (and expensive) equipment exclusively designed for these purposes." (Ibid, p. 19).

"The Verac, constructed by the AVCO Corporation, 1958–1961, could store a million pages in reduced facsimile in a cubic foot of space and could find and display or reenlarge any one of them in seconds. It demonstrated the engineering feasibility of high-density photostorage; in economic terms, however, it was a failure." (Council on Library Resources 10th Annual Report, 1966, p. 21).

"The highly complex hardware necessary to handle ultra-microimages and the quality of the input material must be the two principal criteria against which any plans to use such high reduction ratios need to be checked. I discussed some of the apparent but not real compressions of document systems in the ultra-micro range before the National Microfilm Association last year and will not repeat the arguments here. Project WALNUT, the CIA/IBM high activity document store about which you have read, utilizes a net 35X reduction ratio. The proportion was reached only after having experimented with and found impractical reduction ratios above 50X." (Howerton, 1962, p. 23).

However, it is to be noted that "Republic Aviation entered the microform field because of the large number of technical manuals it provides with its airplane weapons systems. Its equipment records 9801 frames on a 4″ x 5″ fiche at 260 : 1 reduction ratios in a two-stage photographic process. A 10-fiche automatic loader for the keyboard-controlled X–Y positioning "Micro-vue" viewer gives access to any of about 100,000 pages in less than 30 seconds, at a projected cost per page of .001¢." (Van Dam and Michener, 1967, p. 204).

4.8 "The Council has this year commissioned a new investigation from the Republic Aviation Division of the Fairchild Hiller Corporation. This study will seek to identify and estimate the effect of factors (size, contrast, optics, photosensitive materials, etc.) affecting the usefulness of microcopy at high reduction. Film chips will be made demonstrating optimum use of high reductions up to 300, a laboratory model of a viewer will be constructed for evaluating such microimages under various conditions, and an engineering study will investigate the feasibility of procuring hard

copy from the microimages." (Council on Library Resources 10th Annual Report. 1966, p. 50).

4.9 "The importance of high quality in the hard or soft copy output, results from the intensive use which is made of the patent documents. The documents are searched for several hours at a time and the selected documents are carefully studied. A system providing difficult to read copy under these conditions would clearly and rightfully meet strong customer resistance. The maintenance of high quality throughout the system provides a considerable challenge because of the many generations involved in reaching the output copy. Figure 2 shows the steps that might be involved in the production of hard copy in the system. The camera negative would probably not be used in the store because of format requirements and the need for an archival master. The output of the central file, a third generation microform, would be an intermediate whether used for printing, as the input to a Copyflo or Electrofax, or as a master for the production of classified release microforms. The use of video printer does not eliminate these steps, because there is still the requirements for an archival master and because of the need for a buffer between the central file output and the printer. Finally, in the public search application, the remote user should be able to produce hard copy from his soft copy viewer. This would be a print-out from a 4th generation microform." (Urbach, 1962, p. 159.)

4.10 "What are the implications of the *Register* for a national preservation program? One of the first effects will be to bring to the attention of library administrators the need to establish policies concerning preservation of the materials in their collection — all of which are deteriorating at one rate or another. The library community has not yet fully faced up to this need. Some libraries are using their only microform copies as service copies, and, in some instances, these represent the most complete files available, or even unique and irreplaceable copies." (Applebaum, 1965, p. 492.)

"C. S. McCamy . . . [said that indications based on an extensive survey] point conclusively to excessive humidity as an important element in the production of blemishes on microfilm. Laboratory work also indicates that chlorine (as found in urban water systems) is a factor to be considered. Further research must be done, however, before definitive conclusions are reached or any new recommendations are made regarding the production and storage of archival-quality microfilm." (LC Info. Bull. **25**, App., 285 (1966).)

"Scientists at the NBS Institute for Basic Standards are investigating aging blemishes that sometimes form on microfilm years after the films are placed in storage . . . The discovery of aging blemishes on some microfilm has generated extensive research into the causes of blemishes both at NBS and throughout the photographic industry. The objective of these studies is to obtain a clear understanding of the physics and chemistry of the reaction so that proper measures may be taken to prevent blemish formation. . . .

"Research at NSB, at the Armed Forces Institute of Pathology, and at Kodak Research Laboratories has led to the conclusion that biological mechanisms are not directly contributory. All findings thus far indicate the spot formation is a chemical process, and as usual in such cases, the probability of reaction depends on many factors. These include the exposure and processing conditions as well as various aspects of film storage." (Research on Archival Microfilm, 1966, pp. 154–155).

4.11 These techniques were developed, for example, in the Microfilm Rapid Selector as originally proposed by Bush and in the Eastman Kodak Minicard System. For the historical background, see Bagg and Stevens, 1961, pp. 9–36.

4.12 "The merged-record approach, wherein the machine-readable, coded representation of a document is fused together with the full text document image, results in a clumsy, slow-response system which inflicts excessive wear on the document images, and involves great inefficiency and inflexibility in index searches." (Vogel, 1962, p. 27.) In contrast, "physical independence of the index from the related photo images . . . makes it convenient to:

a. Search a great amount of compressed data (indexed information) efficiently, without scanning or physically passing over the great volume of extraneous information contained in full copies of the documents indexed.
b. Reclassify, update and purge sections of the index without altering the image file.
c. Establish as many cross-indexes as may be desired.
d. Index and refer to relevant holdings stored in other forms or in other locations.
e. Add to and purge documents from the image file without regard to fixed categories or file locations.
f. Use the mechanized index in combination with a manned library, or the mechanized image file without the computer-based index.
g. Replace either the index or image file with different units without disrupting the system." (Ibid, p. 28.)

4.12a "Posting document numbers in a peek-a-boo system involves locating, in a rectangular array on an index term card, the coordinates corresponding to the document number and punching a hole at that point on each card applicable to the document. A search will then let light pass through the same hole locations in several stacked cards indicating, with the aid of a grid, (or, as described below, by use of the Microcite search machine) the numbers of those documents indexed by all the terms selected for the search, hence the documents to be retrieved.

"The peek-a-boo or search cards . . . used are 5″ x 8″ x .007–.010″ polyvinyl stock, of which there is one each for every primary index term used . . . Output may be limited to this display

or the user may, by pushbutton, command readout into an IBM punch. The basic elements required for provision of hard copy output have been incorporated in the machine, but this capability has not as yet been used in routine operation.

"In Microcite, the location of each indicated hit is used as a reference point from which to position and project a microfilm image of the abstract of the document, or of data that can be accommodated within the limits of a 5 x 8 inch card in the case of data retrieval systems, for visual inspection by the querist. The searcher may then (1) determine the probable relevance of the projected items to his question prior to retrieval of the full document text, (2) selectively sample the results to ascertain whether his search prescription is too broad, or narrow, and, with collateral use of an indexing term dictionary (coding vocabulary), (3) either reformulate his search prescription in the former case or add and/or remove index term cards in the latter. These operations are possible because the searcher becomes part of a closed feedback loop when he is conducting a machine search; that is he receives prompt indications of the machine output from which he may modify the input. In terms of "directed browsing" (where the user poses a deliberately broad question), a convenient tool is thus provided. In this way the machine provides browsing capability equivalent to access to a very large number of libraries each organized in a different basis at the whim of the user.

"Microcite is therefore a special-case system involving search type selection that not only retrieves address locators, but is coupled with a direct facsimile output of document abstracts or of data (projected image and, if desired, hard copy). It thus uses two basic storage media: vis., film on which the abstracts or data are copied and peek-a-boo cards for indexing. The process for storing the abstracts or data involves a special camera that records each image at the precisely correct location in an array. At a reduction ratio of 64 to 1, 20,000 photoreductions of 5 x 8 inch cards are accommodated in a 15″ x 15″ area on a 20″ x 24″ film sheet . . .

"In operation of the Microcite machine for search, the film matrix appropriate to the peek-a-boo set being searched is automatically selected and mounted on a drum. The operator places selected peek-a-boo cards on an illuminated area of the machine and manipulates two control wheels to position a set of cursors on each illuminated, that is, unobscured hole in turn. Turning the control wheels cause rotation and translation of the drum carrying the film matrix, so that as the cursor is set on each hole, a fullsize focused image of the citation and abstract corresponding to that hole is projected on a screen in front of the searcher." (Adapted from Bagg and Stevens, 1961, pp. 83, 85–86; additional information from J. Stern, Sept. 1969.)

4.13 "The principal factors that determine whether or not a file should be automated are file activity and cost. Although complex centralized storage and retrieval systems have been advocated for many years, (2) the shortest time cycle from question to answer is frequently found to be the use of decentralized microfiche files. Therefore, we can draw the following conclusion: when manual microfiche files are automated, the ideal of having an entire file of information concerning one individual's area of interest can be on his desk, available on simple command, and capable of easy update." (3) (Hoadley, 1966, p. 30).

"Microfiche report dissemination or publishing may reduce the need for remote physical access to central files simply because you literally can store a small library in your desk." (Herbert, 1966, pp. 34–35).

"Obviously convenience of look-up on the premises of his own building will revolutionize the researcher's work and should improve the quality of his work and prevent unwanted duplication; this, after all, is the *raison d'être* of the special library." (Kozumplik and Lange, 1967, p. 67).

4.14 "GPL Division of General Precision, Inc., has developed a system that allows microfilm to be up-dated and corrected without film reprocessing. Only a standard pencil and eraser is needed to add or delete up-dated information. The new system, PARD (for Precision Annotated Retrieval Display), stores up to 500,000 management information items on 5,000 EAM-cards, automatically selects any one card within six seconds, then 300m magnifies it up to 250 times for television viewing, while providing continuous updating capability." (Data Proc. Mag. **7**, 44 (Feb. 1965).)

4.15 "Erasibility is beginning to be offered with certain microforms. For some photosensitive dyes there is a gradual loss of image density with return to reusable state, unless the image is protected or developed. Another erasable medium is thermoplastic, in which an application of heat smoothes out previous modulation and renders the plastic ready for a new recording." (Heilprin, 1961, p. 217). "Thermoplastic recording is permanent within reasonable temperature ranges, and erasures (with degradation) are possible." (Gross, 1967, p. 6).

Another proposed recording-storage development reported with erasure capability is that of the "Photocharge" system invented by Gaynor and Sewell of G.E.'s Advanced Technology Laboratories. This technique utilizes a photoelectronic potential of material in special film so that light and heat together produce a picture consisting of minute deformations on the surface of the film, which can be erased by reheating. (Business Automation **12**, No. 7, 50).

4.16 "One of the major accomplishments of the NCR PCMI process is that it not only permits inspection to occur at any step of the process but it also allows the operator to correct errors." (Tauber and Myers, 1962, p. 403).

4.17 "It is probable that the single most important impetus to the trend of 'live' micro-image systems was the approval and subsequent publication

in 1960 by the Department of Defense of a group of specifications covering a DOD engineering data microreproduction system . . . In late 1962, these specifications were revised and now represent a very important standard for the entire microfilm industry." (Hanlon et al., 1965, p. 5).

"In June 1963, COSATI endorsed a . . . limited set of microfiche standards, specifying reduction ratio, image frame size, and separation between frames. The Committee recommended their adoption by all Federal agencies. In August of that year, Dr. Jerome Weisner, then President Kennedy's Scientific Advisor, made government-wide adoption of the standards a matter of Federal policy and urged development of further standard specifications for reading and printing the miniaturized product and for reproducing full-size copy." ("The New Microfiche Standards", 1966, p. 36).

"A microfiche standard for documents $8\frac{1}{2}$ by 11 inches or smaller has been established by the National Microfilm Association (NMA). The NMA standard identifies four acceptable microfiche sizes: 75 by 125 mm. 105 by 148 mm, 5 by 8 inches, and 3.25 by 7.375 inches. A reduction ratio of 18:1 to 20:1 is specified with a fixed frame size. It was announced that all Government agencies would standardize with the 105 by 148 mm size (approximately 4 by 6 inches) early in 1965." (RADC Summary of the State-of-the-Art, 1967, p. 53).

"Further refinement of the standards which led to the governmentwide adoption of the 4″ x 6″ microfiche has resulted in the publication of *Federal Microfiche Standards*, issued in September, 1965." (Veaner, 1966, pp. 204–205).

"For the first time the federal government is on a standard before too many noncompatible systems get started. Users will be able to purchase reading equipment with assurance of total system compatibility and without fear of early obsolescence." (Yerkes, 1963, p. 129).

4.18 "Librarians with a responsibility for the service or custody of microforms were urged to acquire and maintain a collection of the latest revisions of applicable photographic standards approved by the American Standards Association . . ." (LC Info. Bull. **25**, App. 483 (1966).)

4.19 "The need for a shift to a linework density standard arises from the fact that the lines which we wish to photograph vary widely in reflectance and produce lines of very wide density differences on the film. In fact, measurements have shown that the line densities on negative film of engineering drawings vary all the way from 0.08 for some ink lines to 0.60 for light pencil lines. This wide range of line density is the cause for most of the problems in making satisfactory reproductions and providing a readable image on the reader. It is with the intention of improving this condition that a control over the density of linework is needed. Preliminary studies have already indicated that a maximum line density of 0.25 with adequate background density would bring substantial improvement." (Frey et al., 1962, p. 105).

"The development of any new art usually begins rather awkwardly and, with learning and experience, it and the associated instrumentation is refined. While at the present time we must read the reflectances of several lines and perhaps determine some optimum exposure based on the range of reflectances, there may come a time when we will be able to scan the entire drawing and have an integrated exposure which will be optimum for all the lines on the drawing. The objective should be to find a method of holding line densities through proper exposure, development and drafting techniques to a spread of approximately 0.20 density. While we are placing the emphasis on the control of line densities, we have not entirely eliminated the importance of background because there must be sufficient difference between densities of linework and background to provide adequate contrast both for producing reproductions and for viewing on a reader. If we can hold to a maximum line density of 0.25, including the density of the base, the 0.25 would represent the maximum line density on a microfilm. If we then establish that a minimum line to background contrast difference of 0.75 is required to insure usability, the minimum desirable background density level would be the sum of the maximum line density plus the desirable contrast or $0.25 + 0.75 = 1.0$ density. It is a procedure similar to this that will be employed to determine the background density level, once the line density standard has been established." (Frey et al., 1962, pp. 110–111).

4.20 "National Microfilm Association members including all major equipment producers conferred with government representatives on September 4 and 5 and are close to agreement on basic standards:

a. Microfiche Sizes — 75 x 125 mm (library card), 105 mm x 6 inches, 5 inches x 8 inches, 3.25 inches x 7.37 inches (tab card).
b. Single frame size: 11.25 mm x 16 mm, double 23 mm x 16 mm with one-half mm separation.
c. Reduction ratios 18x to 20x variable.
d. Reference point on microfiche for automation requirements — lower left-hand corner.
e. Layout — Eye legible title on top of microfiche (along longest dimension, micro pages running in sequence below from left to right and downward from row to row." (Yerkes, 1963, p. 129).

"The NMA Standard specification for microfiche is being revised and will include almost all of the agreements reached between the government and the industry and user representatives." ("The New Microfiche Standard Standards", 1966, p. 39).

4.21 "The third major objective, i.e., encouraging manufacturers to reduce costs of microfiche equipment, will not be achieved until a high-volume market is assured." (Schwelling, 1966, p. 36).

4.21a For example, "standards for microfilm are provided in a new publication — Microfilm Norms — issued by the American Library Association. Subtitled 'Recommended Standards for Libraries' . . . [it includes] a list of pertinent standards of the

American Standards Association, the National Microfilm Association, and the U.S. Government. It also provides target descriptions, target and page arrangements, reduction ratios and image orientation, quality requirements for first-generation films, and a section on duplicate films." (LC Info. Bull. **25**, 552 (1966).)

4.22 "The first attempt to list microfilms was the Union List of Microfilms initiated in the spring of 1941 by the Philadelphia Bibliographic Center and Union Library Catalogue. The list was published in 1942 with Supplements 1–5, 1943–47, and was cumulated into the Union List of Microfilms, Revised, Enlarged and Cumulative Edition, 1951, followed by Supplements 1949–52 and 1952–55. There was then a final Cumulation, 1949–59, published by Edwards Brothers in 1961, which includes more than 52,000 entries representing microfilm accessions reported by 215 libraries in the United States and Canada from July 1, 1949, through July 31, 1959. It excludes newspapers, dissertations, and a number of specialized series such as the Vatican Manuscript Codices. In 1948, another important reference source appeared, Newspapers on Microfilm, a listing which has gone through several editions and is now published by the Library of Congress.

"Both the Union List of Microfilms and Newspapers on Microfilm limited themselves to materials reproduced on roll microfilm. The first listing of publications on unitized, opaque microforms (e.g. Microcard, Microprint) was the Union List of Publications in Opaque Microform, compiled by Eva Maude Tilton and published by Scarecrow Press in 1959. There is a 1961 supplement and a 1965 revised edition. These are essentially listings, in dictionary order, of entries appearing in publishers' catalogs.

"In 1961, Microcard Editions, Inc. issued the first list of microform publications to include all methods of microreproduction. It is called Guide to Microforms in Print and appears in February of each year. Basically, it is a comprehensive list, in alphabetic order, of materials which are available on microfilm and other microforms from United States publishers, exclusive of theses and dissertations. It is not a union list but rather a list of publications offered for sale on a regular basis." (Diaz, 1967, p. 212).

"The National Register of Microform Masters should fill an important need as it provides a central listing for the type of microform that has been most difficult to keep track of—that made by a library for its own use. Since the library may have little or no interest in selling duplicate copies, no publicity is given and therefore the existence of the microform does not become widely known, leading to the type of situation wherein one year after Library A has completed filming a lengthy set, Library B begins filming the same set because it does not know of Library A's activity." (Diaz, 1967, p. 213).

4.23 "Perhaps the best source for information and evaluation of current equipment is Library Technology Reports, a subscription service offered by the Library Technology Program of ALA. This service, which costs $100.00 per year, provides libraries with periodic reports on practically anything they are likely to buy including microform reading machines. All machines are given an impartial examination so that the subscriber receives not only specifications about the machine but also a critical evaluation. All tests to date have been conducted by William Hawken, formerly head of Photographic Services at the University of California Library, Berkeley, and a recognized expert in the field of microreproduction. Mr. Hawken has also written Enlarged Prints from Library Microforms (Library Technology Project Publication No. 6), a detailed study of reader-printers.

Another important source of equipment information is the Guide to Reproduction Equipment, edited by Hubbard Ballou, Head of the Photoduplication Laboratory at the Columbia University Libraries. The Guide is published by the National Microfilm Association under a grant from the Council on Library Resources and is now in its third edition (1965). It is probably the best reference source for specifications; it does not, however, give any evaluations. The current edition contains 550 pages and includes descriptions of 292 machines." (Diaz, 1967, p. 211).

"*The International Micrographic Congress* has received a grant . . . [from the Council on Library Resources] to prepare and publish an 'International Guide to Microfilm Equipment'." (LC Info. Bull. **25**, No. 10, 137 (1966).)

4.24 "Let us now turn to the problem of good to excellent microimage production equipment for problem document collections in which the spectrum of best to worst material to be microproportioned is very great. Just now are cameras becoming available which will accommodate such variance of input quality in resolution ranges commensurate with the newer storage vehicles. Cameras with coupled exposure adjustment devices to relieve the operator of the responsibility for judging exposure characteristics of problem documents may resolve this problem with amortization of the added cost of the equipment to be written off fairly quickly in reduction of film spoilage and added good will of the clientele of the service." (Howerton, 1962, p. 25).

4.24a "Eastman Kodak Co. has announced Kodachrome color microfilm for use by business, education and industry. In a recent demonstration, Kodak showed examples of 16mm color microfilm in rolls and unitized in jackets, as well as in microfiche—4 x 6 in. film-cards with rows of 16 mm exposures totalling up to 60 individual images." (Bus. Automation, p. 69, Dec. 1967).

4.25 "The essential feature that is missing from the currently available machines is the ability to scan directly from the pages of a bound book." (Schatz, 1967, p. 19).

4.26 "Data Reproduction Systems, Inglewood, California, brought out two portable cameras, the DRS 8514 and DRS 1117, which could be used to photograph bound volumes owing to a unique design feature: an 'open bottom' which permits placement

of the camera directly over the pages of an open book of any thickness." (Veaner, 1966, pp. 202–203).

4.27 "Capable of being operated by untrained personnel, the camera can copy single page documents, periodicals, or books in a face-up rather than a face-down position. An even-pressure system holds bound volumes precisely positioned for exposure, preventing damage to the binding. An electronic flash source supplies uniform illumination without heat." (Houston Fearless brochure, "Books Microfilmed While You Wait by New Camera-Processor", B–102–65A, 1965).

"Houston Fearless . . . announced plans to build a microfiche Camera-Processor expressly designed for library materials . . . The opened book is placed *face up* on the platens and the book holder moves upwards against the glass wedge. This flattens the pages and prevents motion during exposure. Presumably the optical system is designed to 'open' the book page a full 180°. Fully processed microfiches (called Filmcards by Houston Fearless) are produced at a reduction of 18 to 1. Capacity of the camera is 250 precut film sheets of size 105 mm x 148 mm, about 4″ x 6″. Work on this unit is being supported by a grant from the Council on Library Resources." (Veaner, 1966, p. 204).

4.28 "There have been all kinds of medical studies and tests about which is better, negative or positive film. We can't prove much one way or the other." ("Microfilm Experts Scan the Future", 1967, p. 28).

4.29 Cf., for example, the following: "During the past four years, a concerted effort has been made to compile a library of working computer programs appropriate for analyzing social science research data . . . The routines are problem-oriented rather than technique-oriented. The organization of the library and its documentation reflect an assumption . . . that users will start with a statement of their overall research objectives and infer from these objectives which routine or set of routines would be appropriate to analyze their data. In fact, several routines ask the user while he is conversing with them on-line to select the kind of analysis he would like to perform . . . It is assumed that social scientists will tabulate or cross-tabulate their data in ways which will facilitate a test of their research hypotheses. The tables so created will then contain direct observations or category frequencies arranged by variables, by categories, or by sub-samples, whichever is appropriate to testing the research hypothesis previously formulated. The routines, in turn, reference and discuss these data according to the structure previously set down by the user . . . Once the routine has been initiated, detailed instructions are given by the routine itself concerning its purpose and scope, its restrictions, the proper way to enter data (with error diagnostics if errors occur), and the proper way to interpret results . . . Analytical flexibility is provided by frequent choice points programmed into the routines themselves such that the user may decide on-line what kind of analysis to perform next conditional upon the results of previously performed analyses . . . A fourth objective was to incorporate as fully as possible into the logic of each routine whatever automatic decisions could be made strictly on the basis of problem and data descriptions provided by the user (e.g., whether to compute a binomial sampling distribution or to approximate it with a normal distribution, depending upon the sample size)." (Miller, 1967, pp. 1–2).

4.29a "The great interest that has been aroused by the proposal of a National Data Center holds great promise and great problems. At the heart of the issue is the juxtaposition of conflicting values—the protection of privacy as opposed to the need to discover new knowledge. We have considered one possible means of partially reconciling these conflicting values, namely, the use of partial aggregation which obscures individual identification. Partial aggregation has the great advantage of satisfying all but the most severe of requirements for the protection of privacy while still offering great improvement over the data which are currently available to the research community." (Feige and Watts, 1967, p. 16).

Many of these issues of privacy and protection will be discussed in a later report in this series.

4.30 "The first Rapid Selector was constructed at M.I.T. during the period 1938–1940 by Bush and his assistants. Figure 8 is a schematic diagram of the original Bush Rapid Selector. In this original version, the microfilmed file consisted of document frames accompanied by specific patterns of clear dots used as a selection code. The code pattern consisted of 12 fields, each of which contained 27 discrete indexing areas. Each area represented a different indexing character. This pattern could be used to identify each document by serial number, name or title, author, or subject content indicia. In this machine, the code appeared on one longitudinal half of a 35 mm film and a photographic image of the original document was recorded on the other half, as shown in Figure 8.

"In searching, the code pattern for each document frame was projected onto a bank of photocells. The photocells were masked by a cutout that was the exact physical image of the selection criterion code pattern. Recognition would therefore occur whenever match resulted in all photocells being illuminated. Such a match fired a strobotron that projected the selected frame (document-record half) onto a section of hitherto unexposed 16 mm microfilm advanced to proper position, thereby allowing a replica recording to be made. Thus, the result of finding a desired documentary item was to copy it when it was appropriately positioned in the selection-mechanism. This preliminary Bush Rapid Selector was used experimentally by the U.S. Department of the Navy during the early years of World War II and subsequently was returned to M.I.T., where it is now stored." (Bagg and Stevens, 1961, pp. 19–20).

4.31 "Randomatic Data Systems of Trenton, N.J., has introduced a completely new line of random card file equipment featuring a 2-second

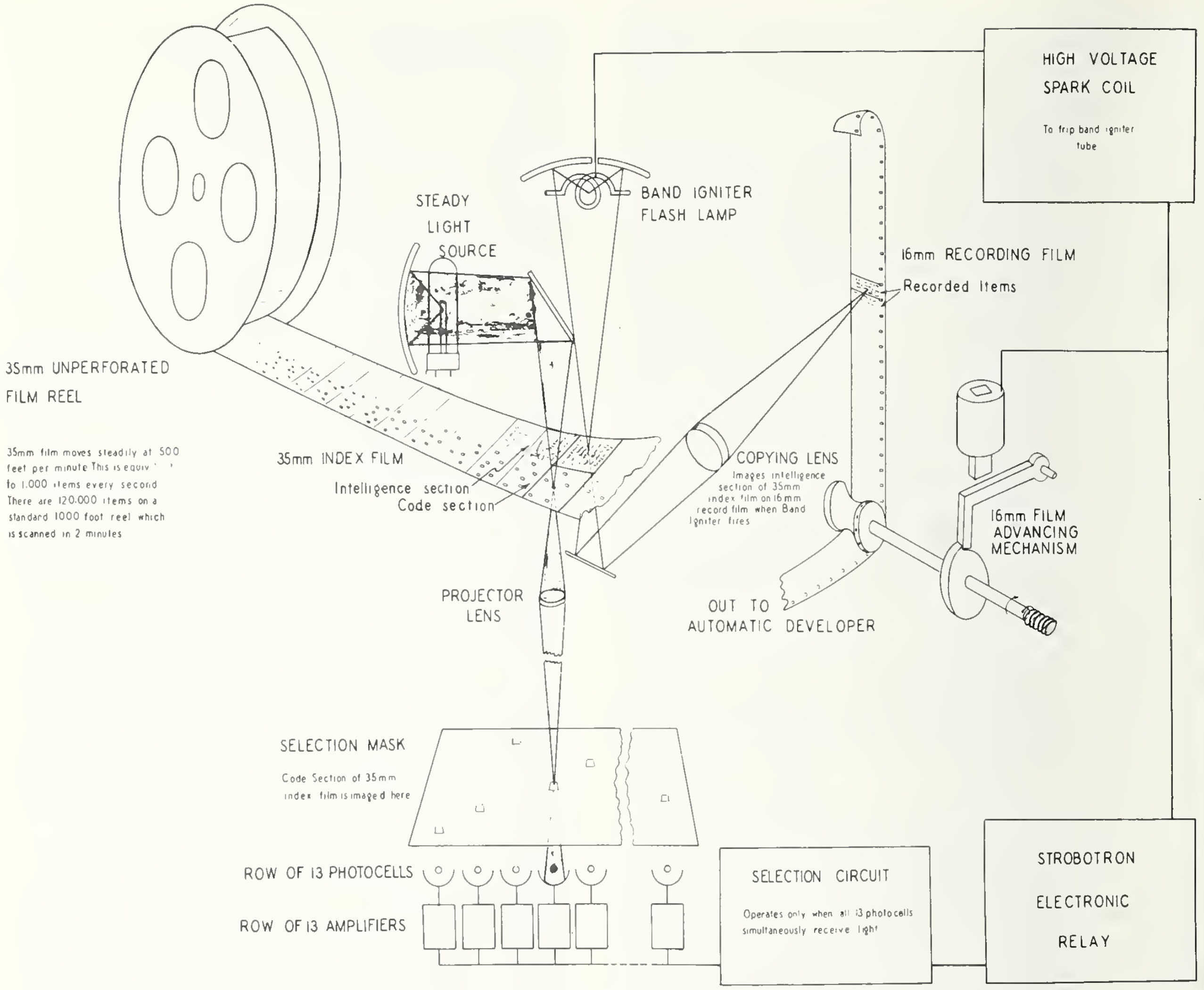

FIGURE 8. *Schematic diagram of Bush rapid selector.*

automatic retrieval of randomly filed cards. A unique concept of coding ordinary cards, by notching them along the bottom edge in such a way as not to interfere with their use in most other card processing equipment, is used. Both notching and selection are performed on a simple 10-button electrical keyboard." (Data Proc. Mag. **7**, No. 11 (1965).)

4.31a "The Microstrip System, offered by Recordak Corp., uses foot-long plastic holders for storage and retrieval of 12 in. strips of 16 mm microfilm . . . File categories are distinguished by color coding on the end tab, which contains an index by content. The plastic strips are also indexed lengthwise to facilitate location of the desired image." (Business Automation **12**, No. 7, July 1965).

4.31 "An information bit is represented by a diffraction-limited 'hole' within the Unidensity film layer. It results from the evaporation of the Unidensity medium by means of imaging the aperture of a laser to a three-dimensional ellipsoid of revolution (Debye ellipsoid). During the time required to create one bit, the vacuum temperature of the laser image if 3 x 10^4 °K produces a vapor pressure of 1000 atmospheres within the bit volume, leaving an ellipsoidal hole in the Unidensity layer . . ." (Becker, 1966, p. 711).

4.31c They conclude: "While it will take considerably more work to make systems of this type that are operationally foolproof, experience has indicated that the principles of operation are sound and that by using this type of system, much of the high-storage potential of fine-grained photographic materials can eventually be realized." (Lamberts and Higgins, 1966, p. 733).

4.32 "Actuators may become very important items of output equipment for the information retrieval field in the near future. When combined with digital to analog converters, actuators can enable an automatic computer to control the operations of machinery and processes. To date, they have generally been applied to industrial use. However, they may become quite powerful in the future in

linking digital information retrieval systems to graphic document retrieval systems. It is not difficult to conceive of a literature search being done by traditional computer techniques with the results of the search being used to produce microform copies of documents from a mechanical graphic retrieval system, the necessary linkage being provided by a computer-driven actuator." (Austin, 1966, p. 243).

4.33 "Data within a given magazine may not be sequentially ordered by any criteria. Serial numbers may be entered on each page of the data by various numbering techniques—including automatic numbering coincidental with feed input at the microfilmer. Alternatively, we may place a numbering counter in the photographic field and sequentially number images that way. During filming, we may enter also what we call an 'image counting mark' for each image. The marks set up the possibility for entirely automatic finding of images. . . . This is the Lodestar Reader with an automatic image finding device coupled to it. There are a variety of quite practical ways that the operator may know the image frame numbers desired. She enters the number—any number up to 10,000—on the keyboard . . . Then she depresses the 'go' button and the correct image appears on the screen in an average of five to ten seconds—depending on the location of desired image within a particular roll of film . . .

"Before leaving the subject of magnetic tape and computers for the storage, and retrieval of information, a few comments may be appropriate. Up to 6 full 2400′ reels of magnetic tape are required to store the data which can be recorded in human language and stored in a single 100′ microfilm magazine. Magazine High Speed Retrieval of desired information may be accomplished in a matter of seconds and at a very low relative cost. Compare for a moment the paper print-out volume represented by approximately 2500 8½″ x 11″ pages with a magazine of microfilm having the same capacity. These and other cost and systems advantages are made possible through the use of film magazines." (Brunelle, 1962, p. 87, 91).

4.34 "The VSMF System, a copyrighted information retrieval system owned by Information Handling Service, Englewood, Colorado, or IHS, has three main elements—microfilmed data in cartridges or cassettes, a printed index for locating groups of desired data, and the microfilm reader printer. As the microfilm is scanned rapidly a heavy black line appears on the reader-printer screen, traveling up the face of the screen, which has a ruled index beside it. As the index line approaches the desired number group on the ruling, the scan rate is slowed until the operator is able to stop at the desired number. Skilled searches can go from fast scan to the desired number almost instantaneously." (Peirce and Shannon, 1967, p. 266).

"More than 15,000 suppliers are supplying data for VSMF files, including scientific and technical data on almost every product used in industry. IHS classifies, indexes, microfilms and distributes the data. The information is indexed by multiple terms which describe the parts, materials and subsystems and manufacturers needs. The film cartridges and VSMF index are updated regularly and airmailed to subscribers to the system. Data is located on a given product in about half a minute. At the moment, VSMF essentially serves product design, plant engineering, and purchasing groups in defense, aerospace, commercial and industrial manufacturing and support organizations. . . . VSMF . . . consists of a copyrighted product index which lists products by type; a microfilm cartridge library of technical data; a full-size viewer, which enables a user to locate required data, and an automatic print copier." (Christian, 1966, pp. 12, 15).

4.35 "For 16 mm film only, 3M offers another reader/printer, the Filmac 400 . . . With a cartridge system designed to compete with the Recordak Lodestar." (Veaner, 1966, p. 202).

4.36 "The most successful of the systems built around roll microfilm is the Recordak MIRACODE which combines the search function with document retrieval. It uses 100-foot cartridges of 16 mm microfilm. Each cartridge contains 2000 images, any one of which can be retrieved by attribute(s) in 10 seconds and either viewed or copied." (Berul, 1968, p. 30).

"The Microstrip System . . . Foot-long strips of 16 mm microfilm are inserted into grooved plastic sticks after a small plastic button is first fastened to one end of the strip. The plastic stick is inserted into the reader and a pointer which engages the plastic button is pushed along the stick. This allows the reader to scan the contents of each strip on the screen. The system is said to be designed for quick look-ups and 'frequently changing' files." (Veaner, 1966, p. 202). See also note 4.31a.

4.37 "A new records retrieval system called Remstar is now available from Remington Office Systems. With Remstar, closed circuit television is combined with automated records retrieval units to not only locate records, but to transmit them as well.

"With this system, the files are centralized and housed in Remington's electro-mechanical units. After retrieval, the record is transmitted on a Remstar Transmitter to a Remstar Monitor which can be placed wherever the record is needed. After viewing the record is released, or, if needed, a copy can be made on the Remstar Printer. A variety of automated file equipment for the Remstar System is available to meet the needs of any size business." (Systems **7**, No. 2, 6 (Feb., 1966).)

4.38 "As many as six million records can be stored in 100 square feet of floor space with the Randtriever system . . . Any one . . . can be retrieved by pushing a button on the input keyboard or by inserting a punched card into the request reader. Electronic memory banks in the system take over to retrieve and deliver the request record." (Systems **8**, No. 2, 6 (1967).

4.39 "The Selectriever, introduced by Mosler Safe Company of New York in 1965, provides for 6-second needle-sort retrieval of any one of up to 200,000 aperture, microfiche or tab cards, which are stored in 100-card cartridges. This wholly automatic unit . . . can also be interfaced with a computer, hardcopy printer, remote displays, or facsimile transmission system." (Van Dam and Michener, 1967, p. 202).

4.40 "The difficulty of reel film for updating might be overcome by the use of microfiche as in the Houston-Fearless CARD (Compact Automatic Retrieval Display) system. Such a system could also be computer manipulated, affording faster scanning access and a more dynamic interrogative process." (Taylor, 1967, p. 31).

"Houston Fearless Corporation . . . announced for delivery in 1967 a desk-top microform retrieval unit and reader, with any of 73,500 (750 fiche with 98 images each) accessible in less than 5 seconds. The unit . . . will be available with an optional hardcopy printer or with a teletype or CRT for on-line hookups. Edge-notched identification numbers are stored on the metal frame surrounding the microfiche, and the search request for a random page, or a next page, is entered via keyboard, paper tape or computer, thus maintaining file integrity." (Van Dam and Michener, 1967, p. 202).

"Houston Fearless demonstrated a breadboard model of CARD (Compact Automatic Retrieval Device), a desk-top unit capable of displaying within 4 seconds any one of 10,000 pages of filmed data. The recording medium is standard 4" x 6" microfiches, mounted in metal holders housed in magazines holding from 128 to 1,024 microfiches. Each metal holder is edge-notched for retrieval purposes and is magnetically suspended so that microfiches do not scrape against each other as they are withdrawn and replaced." (Veaner, 1966, p. 208).

"The Compact Automatic Retrieval Display (CARD) system is produced by the Houston Fearless Corp. Selling at under $5,000, it has a capacity of 73,500 pages and a response time of less than five seconds. Document address is entered by keyboard, however, it could be adapted to accept paper tape, or signals directly from a computer." (Berul, 1968, p. 30).

4.41 "Magnavox delivered to the Army Missile Command its DARE, a high speed, unitized system for storing and retrieving engineering drawings. The DARE (Documentation Automated Retrieval Equipment) is equipped with several hundred magazines, each holding 3,000 35 mm x 3" chips containing a drawing plus coded data. A chip is accessed directly, and copied onto an expendable aperture card within one minute. Besides rapid retrieval, the main advantage of the system is that the master copy need never leave the main file." (Veaner, 1966, p. 207).

"The Magnavue System is utilized by the U.S. Army Missile Command in their DARE program for the processing of a large file of engineering drawings and associated documentation. The computer controlled DARE system provides automatic collection, storage, retrieval, and preparation of punched Diazo copy card outputs from a rapid-access file with a capacity of 750,000 microfilm images. On a random basis, the equipment provides an average access time of 50 seconds. In the normal sequential 'batch processing' mode, a file of 750,000 microfilm images can be processed in approximately 7 hours. The daily sequential processing includes, on the average, the output of 5,000 Diazo copy cards, the input of 2,000 new Magnavue film chips to the system, and the removal of 1,800 Magnavue film chips from the system.

"Magnavue film chips, held in 2,500-chip magazines, are 35 mm wide by 3" long and have a mylar base. The film chip has a high-resolution image portion for the storage of a standard 35-mm microfilm image and a coded portion for the storage of 80 alphanumeric characters that identify the associated microfilm image. The system also can use magnetic chips of the same size to store additional information associated with a given document." (Van Dam and Michener, 1967, pp. 202–203).

4.42 "Alder Electronic & Impulse Recording Equipment Co. is marketing a 'dial-a-document' system for retrieval by telephone of full size documents stored in a centralized microfilm center.

"Called the Alden/Miracode System, the equipment is a combination of Eastman Kodak Co.'s Miracode microfilm retrieval system and an Alden Alpur-Fax Facsimile Scanner which scans, onto high-speed magnetic tape, a facsimile picture of the original document. The tape then is used to transmit the picture over standard telephone circuits to subscribers." (Systems **8**, No. 1, 7 (Jan. 1967).)

4.43 T. C. Bagg, private communication, Feb. 13, 1968.

4.44 "Ampex Corp.'s new Videofile document filing and retrieval system, a completely automated micro-filing system, stores documents as recordings on magnetic video tape and provides fast, automatic access and unusual flexibility in file organization." (Data Proc. Mag. **7**, No. 11, 56 (1965).)

"The Ampex Videofile system is now capable of selectively recording a single page at any predetermined spot on magnetic tape . . . It is understood that at least one major university library is considering the Videofile as the next step beyond the computer-produced printed book catalog." (Veaner, 1966, p. 207).

"Ampex's Videofile system, used in a NASA engineering library, is particularly suited for real-time retrieval of documents with a very short life span. Indexing can be done numerically or alphabetically using 18 numeric or 12 alphanumeric characters stored contiguously to images on (magnetic) video tape. Access to a document can be remote, with hard- or soft-copy output, and the average access time ranges from 11 seconds for the 5-inch diameter, 10,800-page-capacity reel, to 115 seconds for the 14-inch, 259,000-page-capacity reel.

One page is stored on about a third of a linear inch of standard 2-inch wide tape." (Van Dam and Michener, 1967, p. 203).

4.45 "At Republic Aviation, we have determined that many users want the ultrahigh density that a system of our type offers . . . A test program which will be starting shortly will have an ultimate requirement for updating 50,000 pages of repair parts listings every three weeks and distributing the ultrafiche to 3,000 centers. For a program like that, ultrahigh density is a must. A portable device that can give the customer parts and pricing information within a maximum of 30 seconds from a 50,000 page internally stored library is a real plus . . . It is a truly automated random address device that displays the image full scale after it has been reduced 260 diameters. Its trade name is Micro-Vue . . . In order to shoot down original material 260:1 and then bring copy back 260 times, automatically screens out much existing poor quality microfilm material. As for the hardware, automatically handling very high density information is not achieved at low cost. Since Micro-Vue is basically a digital logic driven platform, moving in row/column coordinates under high quality microscope optics, dictates that the price of the viewer will never get down remotely into the $100 range . . . The process which Fairchild Hiller is willing to sell to users allows the laying down of 10,000 images on a glass master within a one-day period with an accuracy of ± five microns on frame centers." ("Microfilm Experts Scan the Future", 1967, p. 29).

4.45a "Ford Motor Co.'s Autolite-Ford Parts Div. has signed a contract with the National Cash Register Co. to transfer parts catalogs to a micro-image dissemination and retrieval system.

"The parts catalog system, based on NCR's PCMI process, provides for filming 14,000 catalog pages covering automobile and truck parts. With the PCMI process, 2,560 pages can be recorded on a single 4 x 6-in. transparency; the 14,000 pages can be put on seven transparencies.

"Initial distribution to dealers will require up to 70,000 transparencies, with a set of one to seven for each dealer. Readers will be leased to Ford by NCR. After original conversion, NCR will provide up to 500,000 additional transparencies a year covering catalog revisions." (Business Automation **15**, No. 3, 88 (Mar. 1968).)

4.46 "A novel technique devised by Aeroflex Laboratories, Plainview, N.Y., permits recording up to 500 different pictures on a single negative. Film is processed in the usual way but is read on a special viewer which allows the user to select any 'page' at random." (Veaner, 1966, p. 207).

4.47 "General Electric's Advanced Development Laboratories . . . announced two other developments. One is Photocharge, a new photographic recording process. Unlike other electrophotographic processes such as those using selenium, or coated paper, Photocharge material requires no external charging to activate the recording process. The second announcement describes improvements in Photoplastic Recording, a process first brought out by General Electric in 1963. Both processes are dry and produce high resolution images almost instantaneously; both require further development before becoming commercially available." (Veaner, 1966, p. 208).

4.48 "IBM's 'Cypress' system ('Son of "Walnut"'), announced (and withdrawn) in 1966, has storage facilities for half a million images on Mylar-based chips. For retrieval, a cell (cartridge) of 35mm x 70mm chips is located under computer control and is transported pneumatically to a copying station, where the selected chip is copied onto an aperture card, which is in turn, transported for subsequent viewing or reproduction. Total retrieval time for this random access system is between 4 and 6 seconds." (Van Dam and Michener, 1967, p. 203).

For a discussion of the earlier "Walnut" system, see Vogel, 1962. For example: "The image converter incorporates eight exclusion switches which represent eight document classifications, each assigned a numeric group code. The classification codes, punched in the input control card, cause the input converter either to skip over these images or to transfer them, as desired. This permits grouping like documents in a given cell. In addition, an X-punch in the card provides for excluding poor quality microfilm images." (Vogel, 1962, p. 37).

4.48a "Data is stored on a 1.38 x 2.75-inch silver halide photographic film chip. Thirty-two chips, containing a total of approximately 150 million data bits, are stored in a small plastic cell. . . . The first cell contains 2250 cells and houses the pneumatic blowers for cell transport. Additional files containing 4500 cells each may be added to increase total on-line capacity. A manual entry station on one or more of the files permits entry and removal of cells from the system. Any cell can be accessed and delivered through the pneumatic tube system to a reader in less than 3 seconds." (Kuehler and Kerby, 1966, p. 735).

4.49 "Magnetic cores have remained the most widely used main memory element and current research is developing increasingly smaller cores, making possible faster, more compact memories. IBM has recently developed a core with an outer diameter of only 0.0075 inches, small enough to fit inside the center hole of most currently used cores. Also under development are new organizations of cores within large memories. Innovations in core shapes have been introduced; for instance, the "bi-axial" core is a rectangular block with two holes through it that can be read in about 100 nanoseconds. Magnetic core memory elements in general will be in use for at least the next few years because of the large investment in existing and developing techniques." (Van Dam and Michener, 1967, p. 207).

"A new low-cost mass core memory has been announced by the Ferroxcube Corp. of Saugerties, New York . . . The new memories, dubbed 'Megabit', are offered in modules of five million core capac-

366-108 O - 70 - 6

ities . . . This 5-million-bit size can be expanded whenever desired by adding on additional 5 million bit modules. For current systems, according to Ferroxcude, Megabit 53.12 can cut sorting and merging time by one third thereby releasing vital computation time and extending system efficiency." ("New Mass Core Memory", 1965, p. 40).

4.50 "Bryant Computer Products . . . has announced the availability of a new online, real-time mass storage disk file system, the Model 2A series 4000, capable of storing 3.8 billion bits of data with an average access time of 100 msec." (Commun. ACM **9**, 404 (1966).)

"The disks allow more than 2.5 million 16-bit words or 5 million 8-bit characters of on-line storage simultaneously." (Data Proc. Mag. **9**, No. 6, 8 (1967).)

"A large capacity disk storage subsystem (DS–25) storing up to 800 million characters. 64 simultaneous record 'seek' operations are combined with four concurrent data transfer operations in each subsystem." (Commun. ACM **8**, 343 (1965).)

"A series of large disc memories features storage capacities up to 6.4 billion bits on a single trunk line and a data-transfer rate of a billion bits per second. Basic 6-disc configuration has a storage capacity of 400 million bits, a data transfer rate up to 150 million bits per second, and an average access time of 35 milliseconds. By combining 16 of these files on a single trunk line, an on-line storage capacity of 6.4 billion bits can be achieved. With special electronics, a data transfer rate of a billion bits per second is available. The new memories, designated the Librafile 4800 series, also feature a fixed-head per track, two methods of search and retrieval, and retractable head plates. The 4800's rotating memory element is composed of six aluminum discs coated with a cobalt alloy. The discs measure 48 inches in diameter and ½-inch in thickness. Mounted on a common shaft, they rotate at 900 rpm. Data is stored on both disc faces. Information is retrieved either through fixed-address or record-content search. Search by record-content is said to be the company's exclusive technique for permitting any field to be used as an access key. Only the nature, and not the locations, of data sought need be known. This feature is said to eliminate costly flagging and table look-up programs, saves central-memory space, and permits simultaneous off-line search. Average access time is 35 milliseconds. Librascope Group, General Precision, Glendale, Cal." (Computer Design **4**, No. 11, 83 (Nov. 1965).)

"New disc file memory provides a storage capacity of 200 million bits, a data-transfer rate of up to 42 million bits-per-second, and an average access time of 17 milliseconds. Called the Librafile 3800, the system was designed for use in large scientific computing centers, in message-switching centers, in military command-and-control installations, and in intelligence data processing systems. The mass memory is available in a basic 6-disc configuration which features a fixed-head per track, two methods of search and retrieval, and retractable head plates. Information is retrieved either through fixed address or record-content search. According to the company, search by record-content is their exclusive technique that permits any field to be used as an access key. Only the nature, and not the location, of data sought need be known. This feature is said to eliminate costly flagging and table look-up programs, saves central-memory space, and permits simultaneous off-line search. Librascope Group, General Precision Inc., Glendale, Cal." (Computer Design **5**, No. 2, 66 (Feb. 1966).)

"The [Control Data] 6608 Disk File system contains a double-actuator 72-disk unit with a capacity over a billion bits. The transfer rate is 1,680,000 characters per second. Minimum access time is 34 msec., maximum, 100 msec. Over 5,250,000 characters are available at one actuator position. The two actuators operate independently to provide simultaneous seeking and read/write operations." (Commun. ACM **8**, 723 (1965).)

"Sperry Rand's Univac Div. has introduced the 8410 Disc File for use with its 9000 series computers. The 8410 provides removable direct access storage of 3.2 to 12.8 million bytes, or 6.4 to 25.6 million digits, in packed decimal format. The system includes a master dual disc drive expandable one drive at a time to a total of eight drives. Each drive holds a reversible disc cartridge with two storage surfaces, one of which is on-line. Each disc drive can access 10,000 160-byte records plus an 8,000-byte fast access track. Average time to locate and read a record on a random basis is approximately 135 milliseconds. A high speed buffer permits all disc reading, writing, checking or searching to be performed simultaneously with 9200/9300 processing and peripheral operations." (Business Automation **15**, No. 3, 68 (Mar. 1968).)

"Caelus Memories, Inc., has announced that its six-high magnetic disc packs are now in production. Each unit is designed to function with IBM 1311, IBM 2311 and compatible equipment. The 10 coated surfaces in the CM VI disc pack each has 203 tracks of information, capable of storing up to 14.5 million bits. Access time is in the 75–85 millisecond range. The pack rotates at either 1,500 or 2,400 revolutions per minute. The units, weighing 10 pounds per pack, are shipped in sculptured and ribbed styrofoam containers." (Business Automation **15**, No. 3, 80 (Mar. 1968).)

"A new, low-cost, direct access storage system designed for the UNIVAC 9000 series computers has been announced by Sperry Rand's UNIVAC Division, Philadelphia, Pa. The new system, known as the UNIVAC 8410 Disc File, makes it possible for users to bridge the costly gap between punched card and direct access processing. Suitable for field-installation on any UNIVAC 9200/9300 System, the 8410 Disc File provides removable direct access storage of 3.2 to 12.8 million bytes, or 6.4 to 25.6 million digits in packed decimal format.

"A basic 8410 System includes a master dual disc drive expandable one drive at a time to a total of eight drives. Each drive holds a reversible disc

cartridge with two storage surfaces—one of which is on-line. By interchanging disc cartridges, unlimited storage is provided for applications which require serial processing.

"Each disc drive can access 10,000 160-byte records plus an 8000 byte fast access track called the Fastband. All disc drives contain a fixed head for reading and writing on the Fastband and a movable arm with two heads for the remainder of the disc surface. The average time required to locate and read a record on a random basis is approximately 135 milliseconds. Fastbands can be used for program storage, index tables, or storage of frequently accessed data files.

"Another feature of the UNIVAC 8410 Disc File is a high-speed buffer permitting all disc reading, writing, checking, or searching to be performed simultaneously with 9200/9300 processing and peripheral operations." (Computers and Automation **17,** No. 2, 46 (Feb. 1968).)

"A high-capacity random access DISCfILE memory system designed specifically for time sharing applications has been announced by Data Products Corp., Culver City, Calif. The Model 5085 time/share DISCfILE stores over 5 billion bits, and has lower access times and greater operational flexibility than has been previously available to the industry.

"The modular concept of the new DISCfILE permits preventive and corrective maintenance to be performed upon individual components while remaining modules are operating on-line with the computer. Each positioner module can be withdrawn, and individual heads, arms, or associated electronics can be serviced without shutting down the system. Preventive maintenance devices are incorporated so that failures can be anticipated and avoided.

"The system includes eight independent positioner modules accessing 32 discs. Each positioner module carries 32 heads which access data on the eight surfaces of a four-disc group. Each positioner is independently addressable and electrically detented, so that all eight positioners can be simultaneously placed in motion, effectively overlapping seek delays. An option is available to operate up to eight heads in parallel from each positioner module.

"Random average position time is 60 milliseconds; track-to-track time is 15 milliseconds; full-stroke time is 100 milliseconds. These values include time required to move the positioner and completely settle on track; reading or writing can then proceed immediately.

"Control units will be available that are compatible with existing systems using either fixed or variable length records. These provide address processing, data formatting, comprehensive error checking and off-line testing capabilities. Thus the 5085 directly interfaces with existing hardware and software." (Computers and Automation **17,** No. 5, 61 (May 1968).)

"Two removable-medium devices that have been recently marketed are the Anelex 80 series disc and the IBM 2314 Direct Storage Facility. The latter represents a significant development since, with 1600 million bits of information, it is comparable to some of the large fixed disc in capacity, cost per bit, and average access time for a single piece of information (90 milliseconds); however, since there are eight independent disc packs, each with its own accessing arm, eight different pieces of information can be sought simultaneously; average access time is reduced from 90 to 40 milliseconds. A comprehensive comparison of bulk storage devices appears in Craver." (Van Dam and Michener, 1967, p. 206).

4.51 "[UNIVAC] Fastrand II Mass Storage–129, 761, 280 alphanumeric characters per unit; up to 8 units per computer channel; 92 milliseconds average access time; sector addressable." (Computer News **9,** No. 7, 7 (1965).)

"Replacing the model 7320 for use with the 360/40, 50, 65, and 75 is the model 2303, which can store almost 4 million bytes accessible in 8.6 milliseconds. Transfer rate is 312,000 bytes/second. Capacity is five times that of the older unit, and speed is doubled. IBM DP DIV., White Plains, N.Y." (Datamation **12,** No. 3, 81 (Mar. 1966).)

"A magnetic drum (MD–30) which provides high-speed storage and retrieval of frequently used data and instructions. Transfer rate is 370,000 characters per second. Average access time is 8.5 msec. and it stores up to 12 million characters." (Commun. ACM **8,** 343 (1965).)

"The Honeywell random access drum file provides a medium for extensive file storage. One to eight drums can be connected to a series 200 system, the storage capacity of each drum being 2,621,440 characters which may be divided into 20,480 records, each of 128 six-bit characters. Average access time to data stored on the drum is 27.5 milliseconds and information is transferred to and from the drum at an average rate of 102,000 characters a second." ("Five Compatible Computers . . .", 1965, p. 289).

4.52 "The RCA 3488 is a mass storage and retrieval unit for on-line operation. The data is stored on 16″ by 4½″ magnetic cards which are removed from their magazines for read/write operations. In one unit there are eight (8) magazines with a total storage capacity of some 0.34 x 10^9 alphanumeric characters. In certain arrangements, the total capacity can be as high as 5.450 x 10^9 characters. The average access time is 350 milliseconds with a data transfer rate of 80,000 characters per second." (Bones and Kros, 1966, p. 60.)

"A data cell is divided into 20 sub-cells each containing ten strips of magnetic tape 13 inches long by 2 inches wide. Data are read from, or recorded on, a strip by means of a rotary positioning system which aligns a selected group of ten tapes beneath a read/write head. Access to a specific record takes between 95 and 600 milliseconds depending on the position of the required strip and the arrangement of data in the file . . .

"The 2321 data cell drive has a storage capacity of 400 million bytes . . . up to eight 2321 units may

be connected to a computer, via a storage control unit, providing an overall storage capacity of more than three thousand million alphanumeric characters." ("IBM System/360", 1965, p. 300).

"A magnetic strip mass storage unit (MS–40): Each unit can hold more than 532 million characters, and eight of those units may be used together as a subsystem. This provides random access to more than 4 billion characters." (Commun. ACM **8**, 343 (1965).)

"A CRAM control unit interfaces up to 8 CRAM units to a single position of a Century 100 or 200 I/O trunk. Each CRAM unit stores up to 124 million bytes or 248 million packed decimal digits in a single changeable cartridge. The cartridge holds 384 cards made of Mylar with a magnetic oxide coating. One selected card at a time is dropped from the on-line cartridge and wrapped around a revolving drum; this takes about 125 milliseconds. Then any or all of the data on the card can be read and/or written. Data is transferred at the rate of 71,250 characters per second." (Hillegass, 1968, p. 49).

"Take the face of a king-size cigarette package, coat it on both sides with a magnetic film, and you have a 'file-card' with a potential for storing over 100 times as much computer information as the conventional punched card. Based on a new concept proposed by the United States Army Electronics Command, Fort Monmouth, a new technique in unit record information storage developed by Sperry Rand Corporation's UNIVAC Division (Philadelphia, Pa.), is almost that simple.

"The new technique employs an all-fluidic (air) transport and a pocket-sized card with magnetic recording surfaces. Instead of the familiar 7 x 3 inch paper punched card, the new unit record in the experimental system measures 2½ x 4 inches and is made of a plastic material overcoated on both sides with a magnetic film on which digital data is recorded by magnetic techniques.

"The plastic magnetic record can store 1,000 characters — more than twelve times as much information as a standard 7″ x 3″ punched card — using only 12.5% of its magnetic surface for machine-readable data. (The rest of the card is used to demonstrate the feasibility of incorporating printed, handwritten and pictorial information.) Other benefits of the plastic card include a more rugged construction, a reusable record, and considerable better resistance to heat and humidity.

"The new method of handling unit records takes full advantage of the new but rapidly developing fluidics technology. Instead of electrons — the controlling medium in electronics — fluidics uses air pressure to perform control functions. Simply stated, fluidics is the use of a small, easily manipulated control stream, such as an air current, to control the action of a much larger stream of the same medium. The source of the low pressure air flow is a simple reliable device." (Computers and Automation **17**, No. 5, 66 (May 1968).)

"The basic storage medium of these [Honeywell mass memory] units comprises strips of magnetic card, about the size of an 80-column punched card, which can hold up to 117,500 characters each. These strips are housed in lightweight cartridges each of which contains 512 magnetic strips . . . Data are recorded on the magnetic strips in tracks in a serial-by-bit format. Each strip contains a series of notches and when a cartridge is loaded into a unit a series of selection rods are automatically inserted through the notches. The selection rods are actuated and a specific magnetic strip is retrieved by a single program command." ("Five Compatible Computers . . .", 1965, p. 289).

4.53 "This electronic system makes possible high-speed and high-density storage (and subsequent retrieval of digital information on recording media such as thin metallic foils or semi-conductor films).

"The heart of the system is an electron beam tube which produces a spot size of five microns at the recording surface by magnetically focusing the beam. Electrostatic deflection is employed to position the beam wherever required. High-speed accessibility for read-out operations can be accomplished by special circuitry. The device is a rugged and completely demountable unit." (McDonald et al., 1964, abstract).

4.54 "A large scale memory system, which uses film chips contained in plastic cells to store more than a trillion bits of digital information is being developed for . . . AEC [by IBM] . . . Information will be recorded by means of an electron beam which will 'write' digital data on the 35 mm x 70 mm film chips in the form of microscopic black and white coded spots.

"When a piece of information must be retrieved from, or stored in, the mass storage systems, the cells move automatically, under program control — to photoelectric reading and writing stations. Data is transferred on-line at high speed between the storage systems and the central computer." (Bus. Automation **12**, No. 8, 62 (1965).)

"The trillion-bit IBM 1350 storage device, an offshoot of the 'Cypress' system . . . uses 35 mm x 70 mm silver halide film 'chips'. A total of 4.5 million bits are prerecorded on each chip by an electron beam. For readout, a plastic cell containing 32 film chips is transported to a selector, which picks the proper chip from among the 32; average access time to any of the 10^{12} bits is 6 seconds. After a chip is positioned, information is read using a flying-spot CRT scanner. Two IBM 1350 units are scheduled for mid-1967 delivery to the Atomic Energy Commission at Livermore and at Berkeley for use with bubble chamber data." (Van Dam and Michener, 1967, p. 205).

4.55 "Another scheme for storing digital information optically is the UNICON system, under development at Precision Instrument Company. This system uses a laser to write 0.7-micron-diameter holes in the pigment of a film. Information is organized in records of at most a million bits; each record is in a 4-micron track extending about a meter along the film . . . Each record is

identified by information stored next to the beginning of that record, in an additional track at the edge of the film. Readout of a particular record involves scanning the identifier track for the proper code and then scanning the track with a laser weaker than that used for writing. It is predicted, on the basis of an experimental working model, that one UNICON device with 35 mm film could store a trillion bits on 528 feet of film, with an average access time to a record of 13 seconds." (Van Dam and Michener, 1967, p. 205).

4.56 "At least two different programs are underway to develop solid-state storage modules that could be plugged into read-write electronics . . . If this proves feasible and economical, the input/output and off-line storage functions presently provided by magnetic tape could be provided by high-speed, high-reliability devices and media with no moving parts." (Hobbs, 1966, p. 38.)

"The goals for one development program of this type are 4 million characters per [solid-state storage] module, read-write rates in the order of 2 or 3 million characters per second, and costs of approximately 0.015 cent per character for off-line storage. A further advantage that would be offered by this particular approach is random access (in 1 μ sec) to any block of data within a storage module on the read-write unit . . ." (Hobbs, 1966, p. 38.)

"The serial data processing applications of the future could well use removable-medium, mass storage devices in place of tape units. On-line, random-access applications could be handled during the day and serial processing at night in a typical system." (Bonn, 1966, p. 1866).

5. Output and Post-Processing Requirements

5.1a "A basic principle of systems design states that no system is better than its final products. It therefore follows that output requirements establish a framework upon which all other elements of systems design must concentrate. Output products must be specified in terms of both content and form. Unfortunately, too many automated systems have not given sufficient consideration to the latter, and although the system may be able to produce the necessary items of information, these are frequently presented in such a way as to be either extremely difficult or in some cases virtually impossible to use. It is also unfortunate that, in this era of modern computer technology, the development of sophisticated output devices has lagged seriously behind other types of data processing equipment. This paper will discuss these problems, and in addition to presenting a detailed review of currently available equipment, will describe some of the more important elements of systems design to be considered in relation to the output of systems." (Austin, 1966, p. 241).

5.1b "University of Pittsburgh. The Computation and Data Processing Center (CDPC) with support from the Advanced Research Projects Agency of the Department of Defense, has developed a system for book and journal printing. Under the leadership of Kehl (now at M.I.T.), this group at first carried on the work begun by Barnett at M.I.T., later developing a separate system, which included use of light pen, on-line typewriter, display scope, and a general-purpose text-editing program for handling the processes of editing, formatting, and introducing author's alterations. Large amounts of 31-channel monotype tape generated in composing The Physical Review were accumulated for conversion to magnetic tape via a special reader built at the Center, to serve as a data base for experimentation. These developments are described by Ohringer, and Roudabush et al." (American Institute of Physics Staff, 1967, p. 351.)

Then we note also the following: "General-purpose displays and, to a lesser extent, alphanumeric consoles can provide an author/editor with implementation of a file organization such as that first described by Bush and more recently by Nelson as "Hypertext": "the combination of natural language text with the computer's capabilities for interactive, branching or dynamic display . . . a nonlinear text . . . which cannot be printed conveniently . . . on a conventional page . . .". Englebart's extensive work on computer-aided text manipulation using a flexible editor's console illustrates this concept. Another summary of on-line process building, information retrieval, and text manipulation is found in Corbin. Magnuski's master's thesis gives overall design specifications for the capabilities of an Information Retrieval and Display terminal, using existing equipment in the context of the MULTICS GE 645 time-sharing system. Research continues on the BOLD (Bibliographic On-Line Display) system." (Van Dam and Michener, 1967, p. 197).

5.1c Thus, "it is not unreasonable to imagine an author, sitting at a typewriter in his own office to be able to edit his manuscript by entering changes for the computer, type requests for bibliographic references from the library, control the format of this publication, and request the computer to produce an index automatically." (Kehl, 1965, p. 26).

5.2 "One of these [CRT] displays was available in 1953 on the ILLIAC . . ." (Frank, 1965, p. 50).

5.3 DYSEAC, later PILOT, and to a certain extent the latter's halfsister machine, Burlesc, at Aberdeen, included, for the relatively early period of their design, unusual features of multiple, variable-format input and output, priority interrupts and control interlocks, and multiprogram swapping and sharing characteristics.

"As an example, before digital computers can be successfully incorporated into the often-predicted

'automatic factory' and 'automatic office' of the future, such equipment must possess ready means for sending intelligence to and receiving intelligence from a variety of external devices performing many diverse functions. Some of these devices will have to store, tabulate, file, convert, display, and sense information; still other devices will have to actuate mechansims such as servo equipment in response to signals sent out by the computer as a result of information being processed within it. The computer will have to direct all these devices and coordinate their activities into an ensemble operation. Indeed, to achieve the full effect of an ensemble operation, the system needs to have the characteristics of a generalized feedback loop. That is, the computer must not only exert control over these external devices, but they in turn must be capable of calling for alteration in the course of action of the computer. Such requests enter the computer as special signals or information transfers from the external devices. . . .

"This feedback arrangement can be used to introduce human monitoring and selective intervention into the normal operation of the system. In its simplest form, pertinent information is displayed to the human monitor who can elect to respond by actuating other external devices that supply the computer with either new data or instructions. This feature will doubtlessly be a highly significant factor in the efficient exploration of the new areas for which digital techniques appear so promising. . . .

"The kind and extent of the external devices to be added will necessarily depend on the particular application which is being explored. Nearly all tasks need some printing and external storage facilities; hence, the initial installation will have a directly connected electromechanical typewriter and one or more magnetic wire cartridges for speedy loading and unloading of the machine. External storage in the form of magnetic tape equipment is also to be included initially in order to handle the more usual computing and data-processing tasks. More demanding tasks requiring somewhat faster access to a rather large volume of data will probably lead to the annexation of one or more magnetic drum units. Still more extensive problems concerned with means for handling masses of paper work will probably lead to the subsequent addition of experimental magnetic disk memory assemblies and experimental versions of the automatic magnetic file. For the exploration of real-time problems, including simulation and control aspects, it will be necessary to annex input and output converters to permit translation of information back and forth from digital to analog form. For example, digital-to-analog conversion is used when visual display of information stored inside the computer is provided externally by means of special cathode-ray tube devices. This listing of external devices includes only those for which serious attention and development are already in progress. . . .

"One further device that may be attached to DYSEAC for special experiments is SEAC itself. As the two machines employ the same digital language, this attachment can easily be made through their regular input-output terminals. By use of a coordinated pair of programs, the two machines can be made to work together in common harness on a number of interesting and potentially useful tasks. Indeed, this mode of operation can, by the application of available technology, be extended to a widely dispersed group of information-processing machines that are interconnected by means of a communication network. With suitable feedback facilities and correlated processing programs these machines could even engage in cooperative tasks for which the supervisory functions are transferred back and forth, as the need arises, among the several machines in the network. These new approaches to the problem of automatizing industrial and commercial operations are reasonable extrapolations of current trends and can be expected to lead to practical results if vigorously pursued. . . .

"As a second example of a potential application which requires these capabilities, consider an installation engaged in the control of air traffic at an airport terminal. For this application, the human operator can be coupled to the machine system (1) through the medium of a visual display device which exhibits graphically the numerical data stored inside the internal memory and (2) by means of a battery of manual control switches capable of inserting new numerical data or certain new control commands into the machine. The numerical data displayed by the machine represent in real time a map of the predicted traffic patterns in the neighborhood of an airport, e.g., the predicted locations, based on latest scheduling information, of all aircraft inside a certain area. The human operator can, by means of the manual input-controls, enter newer data into the machine as the information becomes available, interrogate the machine for more detailed information concerning certain individual flights as the need arises, and instruct the machine to exhibit the effect to be expected from issuing revised flight-control orders. In the latter case, parts of the internal information of the machine must be presented to the operator in a rather complex pictorial form in order to be meaningful to him. Applications of this sort, like the previous one, require a constant interchange of intelligence between the computer and its operator, and between the computer and other devices." (Leiner et al., 1955, pp. 39, 40, 51).

5.4 "A computer system, to work in partnership with a designer, must have several clearly definable capabilities. It must be able to accept, interpret, and remember shape descriptive information introduced graphically. When such a graphical input capability is properly designed, the man-computer combination can manipulate the elements of a drawing in an entirely new way, with a freedom and precision far surpassing what is possible with pencil and paper." (Coons, 1963, p. 301).

5.5 "A display scope capable of generating three dimensional curvilinear figures with convenient control of translation and rotation would be extremely useful. The approach that has been taken is to provide a function generator capable of generating straight lines or second-order curves, and to have special purpose computing equipment in the display unit which can perform the three-dimensions to two-dimensional axonometric projection computations. . . .

"A system is presently being designed for the Electronic Systems Laboratory which will display on a scope a standard two-dimensional plot or a rotated axonometric projection of a three-dimensional line drawing. The system will be capable of generating first- and second-order lines and will provide easy means for the computer to translate or rotate the picture, or to magnify or de-magnify it. Techniques are incorporated to prevent plotting when the limits of the scope edge are reached." (Stotz, 1963, p. 325).

5.6 "Each time a drawing is made, a description of that drawing is stored in the computer in a form that is readily transferred to magnetic tape. A library of drawings will thus develop, parts of which may be used in other drawings at only a fraction of the investment of time that was put into the original drawing . . . A drawing in the Sketchpad system may contain explicit statements about the relations between its parts so that as one part is changed the implications of this change become evident throughout the drawing. For instance, Sketchpad makes it easy to study mechanical linkages, observing the path of some parts when others are moved . . . The ability of the computer to reproduce any drawn symbol anywhere at the press of a button, and to recursively include subpictures within subpictures makes it easy to produce drawings which are composed of huge numbers of parts all similar in shape." (Sutherland, 1963, p. 332).

5.7 "Sketching is facilitated by the computer, which posts a background outline plan having the proper dimensions and showing existing structures that cannot readily be altered . . . On their sketches, which they can readily file away and recall for revision, the planners label the various departments and the stairs, elevators, dumbwaiters, etc. Each label, typed on the typewriter, appears at the top of the oscilloscope screen, and then is adjusted to desired size, trapped by the light pen, moved to its proper location on the plan, and dropped there. Each label serves as a storage and retrieval tag for the sketch to which it is attached. The plan can therefore be made up in small parts and displayed as a whole." (Licklider and Clark, 1962, p. 118).

"The purpose of the BBN time-sharing system is to increase the effectiveness of the PDP–1 computer for those applications involving man-machine interaction by allowing each of the five users, each at his own typewriter to interact with the computer just as if he had a computer all to himself. . . . A 4096 word drum field is allocated for saving the *core image* of each user when his program is not running. A user's program in *run status* is run for 140 milliseconds, then if there is another user also in run status, the state of core memory is stored in the first user's core image on drum and simultaneously the second user's core image is loaded into core and the second user's program is started in the appropriate place." (McCarthy et al., 1963, p. 51).

5.8 "AESOP is an experimental on-line information control system realized in the Systems Design Laboratory of the MITRE Corporation . . . It is a CRT display-oriented system in that the user experiences the information system primarily through his CRT displays and exercises his control through his light pencil. The current version of the AESOP prototype operates on an IBM 7030 (Stretch) computer (65 K memory with 64-bit words) with a 353 disk storage unit holding two million words. Each of the four user stations consists of an on-line Data-Display-13 display console with a photoelectric light pencil, an on-line typewriter, and a Stromberg-Carlson 30370 medium-speed printer." (Bennett et al., 1965, p. 435).

"The AESOP system, developed at the Mitre Corporation, employs an interactive display showing data structures and other aids in query formulation." (Minker and Sable, 1967, p. 137).

5.8a "As we have noted, the MCG [Man-Computer Graphics] concept is relatively new. It first began to achieve significance when I. E. Sutherland presented his 'Sketchpad' work at Lincoln Labs to the Fall Joint Computer Conference in 1963. Lockheed-Georgia began its work in MCG early in 1964 without knowledge of any other industrial activity in MCG. In the fall of 1964, Lockheed-Georgia ordered a Univac 418 and a Digital Equipment Corporation 340 scope. At that time, no computer manufacturer had announced an MCG system. Shortly thereafter, IBM announced its Alpine MCG system, while Control Data Corp. announced its Digigraphic system in 1965, and the General Motors DAC–1 (Design Augmented by Computers) was unveiled at the Fall Joint Computer Conference in 1964. (The GM work had begun about 1959, but had been undisclosed until this conference.) . . .

"One of the first applications envisioned for MCG was the numerical control parts programming function. Conventionally, the parts programmer starts with a blueprint of a drawing and redraws it according to his own needs. He then gives a coded name to each point, line, and arc, and writes a computer program in some stylized language such as APT (Automatic Programmed Tooling) to describe the path a cutting tool must take to cut out the part on a milling machine. This requires conventional batch processing and the usual wait is required to get a plotted output from which the program may be verified. Mistakes require corrections to the program and additional waits for 'batch' output.

"With MCG, the drawing is put onto the display scope by input from cards, light pen, tape, or combinations thereof. The cutter path is depicted on the

scope as the operator maneuvers it with the light pen. Any mistakes in path definition are instantly apparent and may be immediately corrected. As the operator describes the cutter path on the scope, a tape is automatically defined. This tape, when post-processed to adjust to the format for a particular milling machine, is then used to cut out the depicted part as often as is required." (Chasen and Seitz, 1967, p. 25).

5.8b See also Gallenson as follows: "A graphic tablet display (GTD) console has recently been designed to operate with the Q–32 Time-Sharing System (TSS) at System Development Corporation. The successful completion of the task has provided new insights into system design problems involving highly interactive consoles in a time-sharing environment; some interesting innovations in the design of a graphic tablet console; and some solutions to graphic tablet interface problems. . . .

"Employing the tablet display as a projection on the writing surface has improved the 'naturalness' of this I/O device and has encouraged more users. The display hardware is more expensive for equivalent quality of direct-viewing displays, but the additional advantages gained may be justified for given applications. Additional innovations can be introduced to improve the flexibility of the GTD configuration. These include: the projection of slides in conjunction with the CRT image for tablet manipulation; the adding of a color wheel to achieve computer-generated color displays; and the use of a camera to achieve hard copy output from the CRT. Significant improvement in light output of the projected CRT image must be achieved before these additional capabilities are introduced." (Gallenson, 1967, pp. 689, 694–695).

We note also the following: "Work is proceeding on the implementation of an experimental network involving the APEX time-sharing system running on the TX–2 computer at M.I.T. Lincoln Laboratory in Lexington, Massachusetts, and the time-sharing system running on the Q 32/PDP–1 computer complex at System Development Corporation in Santa Monica, California. Initially, a 4KC four-wire dial-up system will be used with 1200-bit-per-second asynchronous modems." (Marill and Roberts, 1966, p. 430).

5.9 ACCESS (*A*utomatic *C*omputer *C*ontrolled *E*lectronic *S*canning *S*ystem) "was developed for use by the Office of Emergency Planning to help provide rapid access to digital and photographic data . . . [It] accepts input information directly from microfilm records of hand-marked documents and digital information either from other machines or directly from its keyboard. It has been used in experimental work at the Bureau to accept such graphical material as specially prepared maps and charts. It will store the information, perform a variety of operations on it, and present outputs either in digital form for use by other machines or in a form requiring no further translation for man. The system includes an X–Y plotter which prepares such output displays as maps, charts, and diagrams." (Direct Communication Between Man & Computer", National Bureau of Standards Tech. News Bull. **50**, 53–54 (Apr. 1966).)

"ACCESS, A DATA-PROCESSING SYSTEM RECENTLY DEVELOPED BY THE NATIONAL BUREAU OF STANDARDS' INSTITUTE FOR APPLIED TECHNOLOGY, represents an advance in communication between man and computers. This system will receive and process data from local and remote sources and can present its output in a form immediately intelligible to the human operator. Access (so-called for Automatic Computer Controlled Electronic Scanning System) was developed for use by the Office of Emergency Planning to help provide rapid access to digital and pictorial data. The ready availability of these data will aid the OEP in evaluating situations during a national emergency. Access accepts input information directly from microfilm records of hand-marked documents and digital information either from other machines or directly from its keyboard. It has been used in experimental work at the Bureau to accept such graphical material as specially prepared maps and charts. Access scans marked documents by means of an advanced version of Fosdic which is a "Film Optical Sensing Device for Input to Computers." Fosdic was initially developed jointly by NBS and the Bureau of the Census for machine reading of census documents." (Computer Design **4**, No. 12, Dec. 1965, p. 12).

"A machine which has been developed . . . as a research tool for the investigation of man-machine techniques involving CRT displays . . . has been designated MAGIC (*M*achine for *A*utomatic *G*raphics *I*nterface to a *C*omputer). This machine combines large-diameter cathode-ray displays with a specially designed programmable digital computer. It is designed as a remote display station and is intended to be connected to a large ADP system via voice quality communication systems." (Rippy et al., 1965, p. 819).

"A presentation can be obtained on MAGIC's primary display in three ways: a previously memorized figure can be obtained from the machine's memory, the operator can draw a straight-line figure by means of the light pen, or a drawing can be assembled from components in the machine's "library" of symbols. In the last method the positioning operations are used to manipulate components and the light pen to connect them. . . .

"The operator can not only position material; he can also shrink, expand, and rotate it. When the drawing has been edited to the operator's satisfaction, it can be returned to the machine's memory. The digital information can be used to produce 'hard' copy also; this has been done by placing it on magnetic tape to drive an X–Y plotter. This capability lends itself to making engineering changes on drawings and keeping up-to-date drawings on the tape for ready inspection and reproduction. It also permits making additions to maps, charts, or floor

plans, a capability which should be useful in charting routes and courses, adding isobars and symbols to weather maps, and recording occupancy assignments." (NBS Tech. News Bull. **50**, No. 8, 135 (Aug. 1966).)

5.10 "The Shared Memory Computer Display System described by Ball et al., used a DEC 340 CRT whose display instructions are stored in an attached PDP–4, which is in turn connected to a larger, batch-processing CDC–1604–A. The display computer receives input from three keyboards, pushbuttons, shaft encoders, three-dimensional trackball (rolling sphere control), light-pen, a RAND tablet, and has 'bell, two-tone gong, telegraph sounder, and other small noise-making devices, operated by relays under program control'. The DEC 338 is a commercial version of this type of system: a small computer dedicated to a CRT to provide flexible display programming." (Van Dam and Michener, 1967, p. 196).

5.11 "Bell Labs has devised a simple and economical console that displays line drawings, letters, and numbers in answer to problems submitted to a computer. Known as Glance, the console can display computed data such as graphs, plots, IC masks, and drawings." (Data Proc. Mag. **9**, No. 6, 3 (1967).)

5.12 "Benson-Lehner Corporation . . . has developed a new solid-state *L*arge *T*able *E*lectroplotter (LTE) . . . [which] affords a complete contouring package for large-scale computer applications for exact delineations in minute detail of surface contours, weather maps, and topographical features. It produces report-quality graphs and maps rapidly and accurately from digital computer generated output tapes. From either program or operator control, it plots points, symbols, or alphanumeric characters, and draws straight or contour graphs from digital input data". (*Communications ACM 8*, 343).

5.13 [Bunker-Ramo 85 Control/Display Console] "Text, symbols, point plots, and lined drawings may be produced on the 12- by 16-inch active display area of the 23-inch aluminized TV-type screen . . . Symbols are generated at the rate of 100,000 per second, may be produced in two sizes, and may be made to blink on the screen." (Dig. Comp. Newsletter **16**, No. 4, 39–40 (1964).)

"A new video display system that provides computer processed information about developing market trends on the New York Stock Exchange has been installed by the Bunker-Ramo Corporation at Shields & Company's new Stamford, Conn., office." (Data Proc. Mag. **7**, No. 5, 12 (1965).)

"A new family of display devices, the 200 series, is being offered by the Defense Systems Div. of the Bunker-Ramo Corp. The display units combine a TV-like screen with a keyboard similar to that of a standard typewriter. Information being entered into the computer or the computer's response are simultaneously displayed." (Data Proc. Mag. **7**, No. 10, 63 (1965).)

"Bunker-Ramo's console—Bunker Ramo landed an Award of Honor for the BR–90 Visual Analysis Console—designed as a man/machine interface for information-handling systems. The console provides all the necessary tools for graphical data analysis, data generation and computer control. . . .

"The console can interface with almost any computer or digital communications system. It uses keyboard buttons that can be labeled by an overlay in natural, problem-related terms to query an associated computer. . . .

"The operator presses these buttons to actuate computer-programmed subroutines; the computer responds in the form of alpha-numeric or graphic displays on a cathode ray tube. . . .

"It is possible to reorient the console and the computer program it controls for virtually any application through keyboard overlays. The two new and significant features of the BR–90 VAC are stored-program logic and combined electronic and photographic displays on a rear-ported cathode ray tube." (Technology Week, Nov. 21, 1966).

5.14 "A display system that provides continuous visual presentation of data from high-speed digital computers has been developed by the Strand Div. of Datatronics Engineers, Inc. . . . The system consists of an input buffer unit, display programer unit, character generator, line generator, and 12-inch screen monitor. In typical applications, more than 1,000 flicker-free characters and line segments may be generated and displayed . . . Special microfilm output from the D–200 recorder is suited to intermediate storage of computer output data." (Bus. Automation News Report **2**, No. 14, 2 (1962).)

5.15 "The Gerber Scientific Instrument Co., Inc., has announced the design and delivery of the first Stored Program Graphic Display System for automatic drafting. Now in operation at Lockheed-Georgia Company, the System will be used initially to lay out full-scale undimensioned structural drawings and contour-lines drawings for aerodynamic testing and structural studies during design of the C–54 logistics transport aircraft." (Comm. ACM **9**, 781 (1966).)

5.16 "Information Displays' high capacity display system Type CM 10001 uses three consoles driven from a common display generator, and the entire system operates on-line with the UNIVAC 1107 computer. Provisions are included for vector writing, character writing, and circle drawings, as well as programable line texture, programable character size and programable intensity." (Data Proc. Mag. **7**, 45 (Feb. 1965).)

"A new computer-controlled display system, the Type CM 10093, will be shown by Information Displays, Inc. . . . The 10093 features a fast response, large screen CRT display, along with high speed character and vector writing capability and program control of size, intensity, and line structure. The completely solid state CM 10093 features a light pen to facilitate man-machine dialogue." (Commun. ACM **9**, 782 (1966).)

"Up-to-the-moment company operating data can be presented on the Information Displays, Inc. . . . Management Display System, IDI Type CM 10009,

shown for the first time at IFIP Congress 65. Driven over Dataphone from a UNIVAC 490 computer, the system can be many miles from the computer. A large (4096 x 30) core memory in the display refreshes the display rapidly at flicker-free rates, while at the same time, accepts low speed Dataphone signals from the computer." (Commun. ACM **8,** 479 (1965).)

5.17 "Informatics Inc., has received over $400,000 contracts from the U.S. Air Force's Rome Air Development Center to evolve a system for on-line computer use. The system to be known as DOCUS (Display Oriented Compiler Usage System), will employ sophisticated display equipment, operating on-line with modern, large-scale computers." (Comp. News **9,** No. 7, 5 (1965).)

"DOCUS, developed by Informatics for the multicomputer complex at Rome Air Development Center, provides a display-oriented man-machine system with some built-in data management functions and a capability to assign functions to control keys at the display and define and execute compound functions based on earlier defined tasks." (Minker and Sable, 1967, p. 137).

"The development of software techniques for on-line information processing and man/machine communication is then the focal point for the Display Oriented Computer Usage System (DOCUS). Techniques are being developed to facilitate the implementation of on-line procedures and the operation of such procedures through a man/computer conversion mode. The users' areas of interest may be related to information retrieval, scientific research, management, or command and control. It is desirable to make these on-line users less dependent upon the professional programmer by simplifying the implementation and reducing the time for programming new applications." (Corbin and Frank, 1966, p. 515).

"DOCUS has been implemented for a CDC 1640B computer to which is attached a Bunker Ramo 85 display console. The techniques which were developed are, however, not restricted to this hardware which has served primarily as a test bed." (Corbin and Frank, 1966, p. 515).

5.18 "A display console combining electronically generated symbols and slide projected images has been announced by ITT Federal Laboratories. . . . The console is called MACC–Modular Alter and Compose Console." (Commun. ACM **9,** 707 (1966).)

5.19 " '3–M', the Minnesota Mining and Manufacturing Company, offers a 'Visual Communications Center' utilizing a desk top projector whose display can be 'written on' and a transparency-copier." (Bus. Automation **12,** No. 10, 60 (Oct. 1965).)

5.20 "A computer-driven display system is scheduled for delivery to the Carnegie Institute of Technology Computation Center in Pittsburgh this Fall by Philco Corporation. The complex cathode ray tube system . . . was adapted from Philco's Real-Time Electronic Access and Display (READ) system. The advanced system will provide a highly effective method of real-time use of time-shared computers . . ." (Commun. ACM **8,** No. 11, 715 (Nov. 1965).)

"In the READ System, the single monitor and light pen is replaced by a group of up to 15 consoles with both keyboard and light pen. These consoles are driven from a single set of display logic which consists of a character generator, vector generator, format generator, control logic unit and computer interface. This system is unique in that the presently high speed of operation of digital logic is utilized to generate characters and vectors at a speed which exceeds the amount of data that can be displayed on a single cathode ray tube. By using this high speed, a single set of generation elements can be used to drive several parallel consoles. This results in very great economy since the generation units form a major portion of the total cost of a display system. The READ System has the ability to display over 200,000 characters per second and over 100,000 vectors per second on the remote consoles. The organization of the system is such that a unique display can be formed on each of the remote monitors or an identical display can be shown on each of the monitors. The common display logic to monitor separation in this system cannot exceed 75 feet. The computer to common display logic connection could be made considerably longer since the data rate is relatively slow between these terminals with an average word time of approximately 15 microseconds. The entire READ System interfaces to a 131 data channel on a DEC type PDP–1 computer. A portion of the 20K memory of the computer is utilized to refresh the display with approximately one third of the available memory cycles used for this purpose." (Scholten, 1965, p. 128).

5.21 "Sanders Associates, Inc., has announced a new line of information display systems primarily designed for use with commercial computer installations." (Data Proc. Mag. **7,** No. 11, 56 (1965).

5.22 "Development of a versatile-display Computer Input/Output Communications Console combining multiple input controls, visual display of entire messages before transmission, and compatibility with a broad range of digital data processing systems has been announced by Tasker Instruments Corporation . . . The Model 544 console can be tied in with up to 15 similar slave subconsoles . . ." (*Communications ACM 8*, 645).

"A high-speed, real-time modular CRT display system that permits the customer to 'build his own' functional configuration is announced by Tasker Instruments Corp. of Van Nuys, Calif. Designated Series 9000 Modular Display Console, the new system features customer options of a customized or any standard keyboard, five other control devices, four display devices, and four different memory subsystems. The Series 9000 Display Console will be shown to the industry for the first time on November 8 at the FJCC in San Francisco." (Commun. ACM **9,** 831 (Nov. 1966).)

5.23 "The IBM graphic data processing system takes advantage of the power of a computer to handle information displayed in the form of sketches, drawings, diagrams and graphs. This system allows scanning of an existing microfilm image or calling out an image stored digitally within a computer, displaying it on a screen, changing the image with an electronic 'pen', and, within seconds, recording the new image permanently on microfilm and reviewing a projection of the image 19 times its actual size." (Data Proc. Mag. **7,** 45 (Feb. 1965).)

". . . [IBM] announces the new, low-cost IBM 2260 display station, which can be linked to an IBM System/360. The new device will make vital information stored in the computer available for review on a 4 x 9-inch screen. The information also can be revised or updated with a display keyboard." (Commun. ACM **8,** 342 (1965).)

"The IBM 2260 enquiry display terminal comprises an input keyboard which is used to enter an enquiry, and an output screen which displays the answer . . . The information is written on the viewing screen at a rate of up to 2,560 characters a second and a total of 960 characters arranged in 24 lines each of 40 characters, can be displayed at one time. . . .

"An even more advanced display unit is the IBM 2250 which has the ability to display graphic images as well as alphanumeric data derived from the computer. The basic console contains a 21-inch cathode-ray tube on which 3,848 characters can be displayed simultaneously in 52 lines with 74 characters per line [using a character generator and optional buffer for image regeneration]." ("IBM System/360", 1965, pp. 297–298).

"A user can transmit messages to other display stations or to the central computer complex from either an alphanumeric or numeric keyboard. The messages are composed in their entirety, displayed for verification and editing, and then transmitted for computer processing and possible display at other locations." (Commun. ACM **8,** 343 (1965).)

"The cursor can be moved to any point on the screen, giving the user freedom to position information wherever he desires or to erase any displayed data. This symbol gives the user the ability to edit and correct alphanumeric charts or listings on the screen, and update information stored in System/360 with these changes." (Commun. ACM **8,** 343 (1965).)

"A computer-directed drawing system which can produce detailed construction drawings 25 times faster than a draftsman was demonstrated recently by Control Data Corp. The demonstration involved computers in the company's Chicago and Minneapolis data centers and the use of long distance telephone lines over which the problem and solution were submitted." (Bus. Automation **12,** No. 7, 55 (1965).)

"Raytheon Co. has recently announced that it has made several improvements on its 520 Computer System. These include a 1-microsecond main memory and a new keyboard-display station which makes possible on-line display and editing. With this new keyboard/display station, programs can be displayed in a format identical to the programmer's coding sheet, and in a data acquisition system, the station can also be used for display of raw or reduced data as the test progresses." (Systems **7,** No. 2, 8 (1966).)

"New data display devices for the RCA 301–3301 processors . . . [consist] of a keyboard, display and memory-logic element connected to a central processor through data sets, voice grade communication circuits and communication buffers . . ." (Data Proc. Mag. **7,** No. 2, 44 (1965).)

"The CRT sets to be designed and manufactured by Univac will be able to display over 1000 characters on a 5″ x 10″ viewing screen. The ¼″ characters are now formed through a stroke generation method. Since the sets will be the major interface point between the users and the computer, a great deal of time was spent during the development and negotiation phases of the study to design a set that incorporates features that recognize human engineering factors." (Porter and Johnson, 1966, p. 81).

5.24 "The automatic drawing of PERT charts was demonstrated recently by North American Aviation . . . The chart is reproduced by General Dynamics/Electronics' SC4020, which prints an image from a cathode ray tube onto a 9″ x 9″ hard-copy or 35 mm film." (Datamation **9,** No. 6, 50 (June 1963).)

"Other applications of visual display . . . alteration of a PERT network to determine the effect of different target dates . . ." (Silveira, 1965, p. 37).

5.24a ". . . Human engineering in the broad sense is a basic consideration in this system concept; the system is required to present to the user the interface which is best matched to the problem and the user's approach to its solution." (Mills, 1966, p. 196).

"More than any other single concept, the man-machine system concept is the one around which most human factors engineers rally. It is perhaps now the core of the field. Thus, all human factors engineering can be thought of as dealing with the appropriate allocation of tasks between assemblages of men and machines, in which the two anomalous components—the man and the machine—are in such an intimate cooperative relationship that the designer is obliged to view them as a single system. Rather than being called upon to adapt a finished machine so human operators can live with it more easily, the human factors specialist wants to be in on the design from the very beginning to insure that best trade-offs between men and machine functions are chosen." (Lindgren, 1966, p. 135).

5.25 "One of the more promising areas of computer use involves the coupling of a man to a computer system for real-time problem-solving where the procedure for solution of the problem is either unknown or involves complex tasks such as pattern recognition, that can best be performed by humans." (Brown, 1965, p. 82).

"Use of the graphical input-output console allows the designer to pause and study his design at all stages in its process without unnecessarily tying up the computer. Furthermore, he can make modifications at any time and be appraised within seconds of the effects of each change." (Hamilton and Weiss, 1965, p. 3).

"Accessibility, provided through some type of remote computing facility such as time-sharing, permits the engineer to *interact* with the computer during the problem solution." (Roos, 1965, p. 423).

"The complex of recent developments centered around time-sharing systems and aimed at exploitation of man-machine interaction is, in the view of many, the most exciting current trend in the computer field, and the one with the most far-reaching implications to each of us as an individual and to society as a whole." (Fano, 1967, p. 30).

5.26 "The IBM graphic data processing system takes advantage of the power of a computer to handle information displayed in the form of sketches, drawings, diagrams and graphs. This system allows scanning of an existing microfilm image or calling out an image stored digitally within a computer, displaying it on a screen, changing the image with an electronic 'pen', and, within seconds, recording the new image permanently on microfilm and reviewing a projection of the image 19 times its actual size." (Data Proc. Mag. **7**, 45 (1965).)

5.27 "A display system that provides continuous visual presentation of data from high-speed digital computers has been developed by the Strand Div. of Datatronics Engineers, Inc. . . . The system consists of an input buffer unit, display programer unit, character generator, line generator, and 12-inch screen monitor . . . In typical applications, more than 1,000 flicker-free characters and line segments may be generated and displayed . . . Special microfilm output from the D–200 recorder is suited to intermediate storage of computer output data." (Bus. Automation News Report **2**, 2 (1962).)

5.28 "The . . . characteristics of the design problem strongly suggest that the process would be greatly enhanced if tools were made available by which the designer could be quickly appraised of the multifaceted effects of fixing any particular variable. Such is the capability of the high-speed digital computer. . . .

"The idea that the designer can (in a CAD system) explore a much wider range of answers to the decision-makers' questions may be an appealing one, particularly because of the vagueness and changeability of the ship's missions at the inception of design." (Hamilton and Weiss, 1965, p. 5).

"The designer or engineer is interested not only in the surface shape, but also in most of the various surface properties: area, volume, mass moment of inertia, cross-section inertia, center of gravity, resultants and equivalent points of application of external loads (both point and distributed loads), cross-sectional views, and views of the surface, including 'hidden lines', as seen from various orientations." (Hamilton and Weiss, 1965, p. 13).

"At the present stage of this project, the quantities of displacement . . . and wetted surface can be evaluated for any hull or portion of a hull; the framework also exists for future subroutines to calculate waterplane inertias, mass inertias, weight of shell plating, and eventually (given some loading patterns), stress distributions in hull plating." (Hamilton and Weiss, 1965, p. 11).

"Arthur D. Little, Inc., is developing under the sponsorship of the Naval Ship Engineering Center, Naval Ship Systems Command, a computerized system for the design detailing of hull structures for naval ships. The system takes its input data from the ship's contract plans, standard design specifications, and parameters; it produces as output working drawings for use in the shipyard, APT part programs for numerically controlled flame cutting machines, and auxiliary information such as center of gravity statements and bills of material and weight." (Cohen et al., 1967, p. 341).

Research at the University of Glasgow is also aimed at the computer design of ships, "from the initial conception of the shape of the hull to the production of detailed drawings of the steelwork." (Commun. ACM **9**, 539 (1966).)

5.29 "CADET [Computer-Aided Design Experimental Translator] systems are aimed at mixed verbal and graphical man-machine problem-solving. . . .

"An initial version of the CADET system is scheduled for operation in the fall of 1965 and will be applied in such areas as three-dimensional shape description, nonlinear electronic circuit design, etc. . . .

"The designer communicates to the computer by moving the Display Console light pen to various positions on the CRT. He indicates the meaning of these positions by pushing buttons while the pen is at the desired locations. . . .

"The PLOT operator is used to create a picture on the oscilloscope corresponding to the graphical language statements . . . It builds a list of 'console commands' (plot a point, or a line, reposition the beam etc.) known as the *display file*, which are interpreted by the display console hardware so producing the desired picture." (Lang et al., 1965, pp. 3, 4, 5, 21, 39).

Similarly "an experimental computer program which determines how to interconnect 80 electronic circuits on a wafer of silicon, and then controls fabrication of the interconnections, was described recently by an IBM scientist.

"The program for the first time permits automatic by-passing of any faulty circuits on the wafer, so that most wafers are usable despite the occurrence of faulty circuits at random positions." (Data and Control **4**, No. 4, 5 (Apr. 1966).)

5.30 It is noted that "Lockheed-Georgia uses a Univac 418 and a DEC 340 display scope with light pen for research design applications for aerospace." (Data Proc. Mag. **7**, No. 5, 8 (May, 1965).)

5.31 "Master dimensioning gives a computer the ability to derive math definitions of complex sur-

faces, and to combine many complex surfaces mathematically to produce a perspective view of an object . . . North American Aviation, Inc., is reported to have used master dimensioning in its design of the B–70 supersonic bomber. Boeing also used master dimensioning for perspective art on a new fighter aircraft." (Gomolak, 1964, p. 68).

"At General Motors in Detroit, the computer-aided design system, GEM, is used operationally in the design of automobile bodies. Among other things, GEM coordinates the artistic and engineering aspects of design, checking, for example, the strength and manufacturability of a fender as soon as the designer has sketched it on the oscilloscope screen." (Licklider, 1965, p. 66).

"Using the 1965 models as a starting point, the designer inserts still another piece of information into the computer. Looking at this year's car, he says, 'Let's see what it would look like if the body were two inches longer, the greenhouse an inch lower, and the fenders wrapped around an additional three inches'. This information in almost this exact language is . . . loaded into the computer . . . When the stylist tells the computer what view he wants, the computer takes the modified master dimensioning data, combines it with the graphics program and comes up with the coordinates needed for the perspective drawing." (Gomolak, 1964, p. 69).

5.31a "Rowland Brandwein, director of research for Span Arch Structures, Inc., Newtown, Conn., has designed a new kind of arched roof with the aid of a communications terminal in his office linked to an IBM computer in New York City. The metal-and-plastic arch is cheaper and easier to put up than conventional ones, and so light that it does away with many of the supports normally used.

"After hitting upon the idea of making an arch by sandwiching an adhesive plastic between thin metal, Brandwein used his terminal linked to an IBM QUIKTRAN center to see if his theory was practical. He not only used the computer to work out the basic methods for constructing the arch, but also to design special equipment needed by contractors for the job and to create instructions for them." (Computers and Automation **17**, No. 5, 54 (May 1968).)

5.31b "At the Atlanta meeting of the American Association of Highway Officials in December, a civil engineer designed a superhighway interchange in ten minutes through an IBM 1050 data communication system connected a thousand miles to the MIT 7094 in Cambridge." (Data Proc. Mag. **7**, No. 2, 7 (1965).)

Another system designed by Nordisk ADB and the Swedish Board for Road Construction has been reported as capable of making automatic "a large amount of the work of road design." (Langefors, 1965).

Other civil engineering examples are represented by the ICES system and by the following:

"In one impressive demonstration, Dr. Sutherland sketched the girder of a bridge, and indicated the points at which members were connected together by rivets. He then drew a support at each end of the girder and a load at its center. The sketch of the girder then sagged under the load, and a number appeared on each member indicating the amount of tension or compression to which each member was subjected." (Teitelman, 1966, p. 11).

"An IBM program, ALDEP (*A*utomated *L*ayout *De*sign *P*rogram) aids the plant or builder designer in developing optimized layouts for various activities to be accommodated within constraints of the space available, including the graphic display of layouts as they have been evaluated." (Seehof et al., 1966, p. 191).

"Graphical I/O appears to have very great potential for the engineering of transportation facilities. A scope with input as well as output capabilities allows easy, positive and rapid change in any assumptions or designs which can be expressed graphically—a highway network, a roadway cross-section, vertical and horizontal roadway alignment, intersection layout. Plotters make possible automatic drafting of final or intermediate designs, even construction plans." (Breuning and Harvey, 1967, p. 261).

"A noted architect is experimenting with the technique for designing apartment houses, office complexes and ideal communities. A major bridge builder is also looking at drafting machines. And one of the leading makers of home appliances plans to use the graphics program for selecting models, along with numerically controlled machining to turn out washers, dryers and refrigerators." (Gomolak, 1964, p. 71).

5.32 "In current practice, the woven design is represented on point paper (graph paper) which has the number of horizontal or vertical lines per inch in the same ratio as the number of weft and warp threads. Each rectangle represents the intersection of one warp and one weft thread, i.e., one interlacing. At each intersection the warp thread may pass over the weft thread or vice versa. This binary choice now represented by painting or not painting the point paper rectangle corresponding to each interlacing. . . .

"In reference 1, the first approach, the pattern is scanned by a 'photohead'. Then it is dissected, within a computer, into small equal parts called shape elements. Each of these parts is then subjected to a pattern recognition routine in order to classify it into a 'primary standard image' category. The set of primary standard images represent various versions of shape elements prepared by the artist. When the shape element is classified, its corresponding secondary standard image is chosen to represent it in woven form. The secondary standard image represents the same shape element with account taken of the laws of weaving (interlacing rules). Each shape element is analyzed in turn, thus producing, in one pass, a complete set of fabric interlacings. . . .

"After the design has been introduced into the computer by tracing or scanning, the CRT is used as

the primary display device. By manipulating the display with function keys and light pen, the designer can use the computer as an experimental designing tool." (Lourie et al., 1966, p. 539).

"He may display the design on a grid with different ratios of horizontal and vertical lines which represent different ratios of warp and weft. He may also alter the number of warp threads per inch to see how the design would look woven with different degrees of coarseness. He may refine the mesh by enlarging the design on the same grid or holding the design constant and imposing a finer grid. The designer may manipulate the display in other ways. He may 'repeat' the design with different spacing between centers; he may specify different lines of symmetry and thus develop a full design from a small segment. Many other techniques can also be made available to him. . . .

"When a set of weaves has been determined, rules concerning the interaction of adjacent weaves must be applied. For example, for structural purposes there is a rule that no warp thread may float over more than n weft threads (or vice versa). A violation of this rule will be pointed out to the user who may correct the situation by altering a specific interlacing with a light pen or by changing the starting position of one or both of the weaves in question. Another example of such rules concerns a special set of interlacings which delineate an area and which are 'shape binders'.

"Programming can incorporate many of the principles of this technique. Refinements may be made by the designer with the light pen. It is this ability to alter and 'touch up' the automated output that gives this system the required flexibility." (Lourie et al., 1966, pp. 537, 539, 542–543).

532a. See also Ruyle et al. (1967) as follows: "Martin has developed a PDP–6 LISP program that converts complex mathematical expressions stored in a list structure form into a CRT display that is quite close to textbook mathematical notation, and with which the user can interact by means of a light pen." (Ruyle et al., 1967, p. 166; ref. is to Martin, 1966).

"The AMTRAN computer system is a time-sharing, keyboard computer system which permits a scientist to enter mathematical equations into a computer in their natural mathematical textbook format and, barring complications, to obtain immediate graphical and alphanumeric display of the solutions on a cathode ray scope and a typewriter. The system can be used for straightforward problems by a scientist with no previous computer experience while, at the same time, it provides the flexibility required by the experienced programmer to solve non-routine problems. Great improvements in convenience and accessibility as well as in programming and turnaround times accrue to the user in comparison with existing computer systems. For example, a typical nonlinear differential equation can be entered and solved, and permanent graphical and alphanumeric displays of the results provided within minutes.

"A 'demonstrator' version of this system is available for the IBM 1620 computer. The demonstrator uses only the standard computer console typewriter and card reader/punch, and does not require any special equipment." (Clem 1966, Abstract, p. 116).

5.32b "The AMTRAN (*A*utomatic *M*athematical *TRAN*slation) System has been developed at the NASA Marshall Space Flight Center in Huntsville, Alabama and has been available on a limited basis to users there since early 1966." (Ruyle et al., 1967, p. 151). See also Reinfelds et al., 1966.

5.32c "The Culler-Fried System is one name for two physically separate but direct descendants of the system developed by Glen Culler and Burton Fried at Thompson Ramo Wooldridge, Canoga Park, California, beginning in 1961. The first of these is the *O*n-*L*ine *C*omputer System (OLC) at the University of California at Santa Barbara (UCSB) which operates on the same computer as the original system. The OLC system is used for research and teaching on the Santa Barbara campus as well as from remote terminals at UCLA and Harvard. The second, an expanded version of the original system, has been implemented at TRW Systems (formerly Space Technology Laboratories) in Redondo Beach, California for the use of scientists and engineers and has been operating since late 1964." (Ruyle et al., 1967, p. 151).

5.32d "The Lincoln Reckoner system has been developed at the Lincoln Laboratory of the Massachusetts Institute of Technology to operate within the APEX Time-Sharing System for the TX–2 computer and has been used by the staff of the laboratory since early 1966." (Ruyle et al., 1967, p. 152).

"The Lincoln Reckoner is a time-shared system for on-line use in scientific and engineering research . . . It offers a library of routines that concentrate on one particular application, numerical computations on arrays of data. It is intended for use in feeling one's way through the reduction of data from a laboratory experiment, or in trying out theoretical computations of moderate size." (Stowe et al., 1966, p. 433).

5.32e "The MAP (*M*athematical *A*nalysis without *P*rogramming System, which operates within the M.I.T. Compatible Time Sharing System (CTSS) at the M.I.T. Computation Center or at Project MAC, has been used in research and teaching at M.I.T. since mid 1964. The system is accessible from any teletype or IBM 1050 terminal that can dial into CTSS, regardless of the physical location of the terminal." (Ruyle et al., 1967, p. 152).

5.32f "The MATHLAB System of Engelman, which operates under CTSS, is an important start toward providing a system capable of providing both analytical and numerical assistance." (Ruyle et al., 1967, p. 166; ref. is to Engelman, 1965).

5.32g "A new user-oriented programming system for the purpose of facilitating the programming and analysis of well-formulated problems has been designed and implemented at Columbia University, Hudson Laboratories. This system consists of a standard Flexowriter modified to construct two-dimensional mathematical expressions and a new programming language." (Klerer and May, 1965, p. 63).

Other aspects of the program at the Hudson Laboratories of Columbia University include the development of auxiliary consoles for "pushbutton" programming, R & D efforts with respect to automatic mathematical text typesetting, and investigation of capabilities for two-dimensional program and text editing. (Klerer, 1966).

5.33 For example, "using an NCR Elliott 4120 with a display and light pen equipment, the NPL will develop methods to aid the computer programmer by allowing him to write, test and edit programs in a high-level language, on-line to the computer. The computer and display will also be used in patten recognition research . . ." (Data and Control **3**, 11, (1965).)

". . . Recent rumors suggest flow charts to be used on oscilloscope terminals for on-line programming." (Burkhardt, 1965, p. 7).

"Other, more radical uses of display devices in debugging are now being investigated. Flow-chart languages, where programs are created on-line by generating a flow chart with a light-pen, are being studied at Lincoln Laboratory and at RAND. A dynamic display of the program state at any point in terms of the flow chart is expected to be a useful debugging tool." (Evans and Darley, 1966, p. 44).

"William Sibley's and Thomas Ellis's on-line programming system, FLOWCHART, in which the flow diagram is the source-language computer program and through which the programmer writes, edits, debugs, and operates the program by sketching and printing with a stylus on a RAND Tablet. The Tablet is a graphical input device that looks like a sheet of paper on a blotter pad but underneath is actually a grid of wires, through capacitative coupling to which an electronic device can sense the position of the stylus." (Licklider, 1967, p. 10).

"Use of on-line graphical displays for flow charting and programming is an interesting application in the computer field. An example of work of this type is that done at the RAND Corporation in which a rough flow chart can be drawn with a graphical input device and displayed on the screen. A computer provides such niceties as straightening lines and squaring boxes. However, the more important function of the computer in this case is to incorporate into a program the subroutines or functions called for by the individual symbols on the flow chart. If the flow chart as drawn by the programmer does not make sense or if necessary information or linkages are omitted, the computer can indicate the discrepancies and ask the programmer for clarification. This ability to provide two-way communication and feedback, which greatly simplifies the user's task, is an important function of most on-line systems—particularly graphic ones. This provides a 'forgiving' system in which mistakes by the user are not catastrophic but are called to his attention for appropriate action." (Hobbs, 1966, p. 1873).

5.34 "The present approach was to define an algorithm capable of one-pass operation on a small (IBM–1620) computer, using a Calcomp digital incremental plotter online to produce the annotated flowchart." (Anderson, 1965, p. 38).

5.35 "Applied Data Research, Inc., . . . introduced AUTOFLOW . . . [which] accepts assembly or higher level languages and produces quality flowcharts for online or offline printing . . . The AUTOFLOW system allocates the necessary size for a symbol, rearranges groups of symbols and draws lines between symbols." (Commun. ACM **9**, 469 (1966).)

"1966 additions to Applied Data Research Inc.'s AUTOFLOW systems were for system 360 COBOL and FORTRAN. (Datamation **12**, No. 11, 93 (Nov. 1966).)

"The proprietary package AUTOFLOW was released in February 1967, having been developed under NASA support. This system produces flowcharts from program units written in MAP/FAP, FORTRAN, and MYSTIC. MAP/FAP and FORTRAN decks may be optionally augmented by special comment cards and codes which will alter the interpretation of the source and thus modify the quality of the flowchart produced. Of course the use of these options requires extra effort on the part of the user. AUTOFLOW also produces a Table of Contents and a Cross Reference Listing. Output may optionally be obtained on the SC–4020 and/or the line printer; the internal tables may be employed to drive either output. Table overflow can occur, but a capacity of 30,000 input cards and 1700 statement numbers is claimed. The output employs variously shaped boxes to represent the action and pays much attention to the location of all boxes, especially transfer points. All boxes are identified by page and sequence number. The contents of the boxes are identified by page and sequence number. The contents of the boxes are language dependent, but clear, and in some cases expanded, reproductions of the source card content." (Abrams, 1968, p. 745).

5.35a "*AUTODIAGRAMMER*/Software Resources Corp., Los Angeles, Calif. This proprietary program, developed by ARIES Corporation and being marketed throughout the western United States by Software Resources, produces accurate and standardized flowcharts of programs written in IBM System/360 Basic Assembly Language. The use of AutoDiagrammer eliminates a significant part of the time needed for program documentation and shifts the burden of flow chart production from the programmer to the computer itself."

(Computers and Automation **17**, No. 2, 47–48 (Feb. 1968).)

5.35b "A new program now available from IBM enables flowcharts to be produced by a System/360 computer. Compared with earlier programs of this type, System/360 Flowchart has more automatic features for labelling and for linking elements of the chart; it also provides for footnotes." (The Computer Bull. **11**, No. 2, 159 (Sept. 1967).

5.35c "It is hoped to generalize the Flowlister so that it indexes a complete program, producing an alphanumerically ordered list of all common assignments and subroutine calls, and a map of the program as a whole. It could also be extended to handle subroutines written in various assembly languages.

"Except for a few small character-handling routines, the Usercode Documenter, Auto-Diagrammer and Flowlister are all written in Fortran." (Roberts, 1967, p. 22).

"One of the early efforts was reported in 1959 by Haibt who was concerned with flowcharting machine language. Although not completely clear, it appears that extensive use of tables was required to produce output on the line printer. Since she felt it undesirable to attempt to describe an entire program unit in one flowchart, probably because of the limitations of the line printer and the extensive detail present in machine language, the decision to produce multilevel flowcharts was necessary. The program featured a sketchy description of the procedure represented by a box. Certainly this output was not at all language independent since cross references were supplied to program listings. Although mention was made in this paper of drawing flowcharts directly from a FORTRAN program, it appears that this feature was never accomplished." (Abrams, 1968, p. 744).

"Knuth, in 1963, reported on a system which produced flowcharts on the line printer if the assembly code were augmented by descriptive comments. No doubt the inclusion of such comments is a valuable tool, but it does require special effort on the part of the programmer and does also restrict generality. Furthermore, his flowcharts were cross-indexed to a flow outline which was in turn indexed to the assembly listing. Each level conveyed more precise information concerning the action within each box. He felt that 'it is unnecessary to specify all the details of a program in the flow outline' and even less so in the flowchart. His requirement of documentation effort on the part of the programmer does introduce the concept of using computer-drawn flowcharts as creative tools in debugging." (Abrams, 1968, p. 744).

"An interesting flowchart-drawing program which draws a picture of the (undirected) branches of a program by disregarding the specific contents of the boxes was reported by Hain and Hain in 1965. A very elegant connection matrix is employed to generate this 'connection graph'. Hardcopy output is produced by an SC–4020 microfilm plotter; thus the output copy can occupy several pages if the size of the program being flowcharted requires it. Even so, they do report a limitation of 200 statements; furthermore, they do not indicate how their program goes about recognizing the branches. Since they claim an application for their program in drawing PERT networks, it is inferred that preprocessing is required by the user." (Abrams, 1968, p. 744).

"A program by Stelwagon called FLOW 2 which produces flowcharts of FORTRAN and FORMAC programs directly from the source decks became part of the open literature in August 1966. Actually this data is deceptive, since the instructions for using the program are dated one year earlier. An amazing degree of flexibility is available to the user of this program, including the option of producing an intermediate flow deck which directly controls the graphical output produced and may be manipulated by the user to improve the esthetics of the topology. Since the graphical hardcopy is produced by an SC–4020, Stelwagon had the problem of page segmenting and referencing to contend with. He has rejected the flow matrix approach as being too consumptive of storage and has, instead, developed a reduced matrix which serves to position branches and boxes in quite a clear output. Using auxiliary memory, he claims to be able to flowchart program units in excess of 2,000 statements. Various shapes of boxes are provided for identification of type of operation. In solving the paging problem, Stelwagon has brought his branch lines out both horizontally and vertically. Thus, if a one-piece flowchart is desired, one obtains a large rectangular mural when the pages are pasted together." (Abrams, 1968, p. 744).

"The present author has developed a flowcharting program MADFLO that produces continuous output on a CALCOMP drum plotter. The use of this completely random-access graphical output device allows the construction of a program which requires no tables or arrays to determine the position of boxes in advance. Following what seems to be a normal mode, single column output results from non-branching, algorithms. Multicolumn output is produced whenever the program contains decision making branches; the number of columns is limited by the width of paper available. The input scanner operates much like the statement recognition phase of a compiler. Only the syntax of the source language statement is examined to determine the shape of box required to properly represent the operation. Since it was desired to make the flowchart essentially language independent, the scanner deletes certain phrases when the statements are lettered within the drawn box. Except for this editing, the entire statement is always lettered out for the user. He can of course ignore any lettering that does not interest him. Some further development of the methods of Rich and Stone may be necessary to achieve less arbitrary line division; also, the relational operators and assignment indicators

present in the source language character set should be replaced with universally-acceptable symbols perhaps taken from the USASCII character set." (Abrams, 1968, p. 745).

5.36 "A computer controlled approach to the logical block diagram construction . . . would have the following advantages:

a. Computer storage of a complete logical design, either on paper tape or magnetic tape. This means that the current design is in one place and prints reflecting this current design would be available for use by all concerned with the design.
b. Easy correction or modification to the design and prompt issuance of revised prints reflecting these changes.
c. The built-in checking of the logical operation of the design to see if, in fact, it does perform as expected. Also the analysis of the circuit for such items as the loading of the output(s) of each unit, and signal delay along various signal paths." (Loomis, 1960, p. 10–11).

"Although a flow chart compiler is not yet available, a graphical circuit simulator . . . has been programmed for the TX–2 computer at Lincoln. . . . This system should be capable of providing a circuit designer who has no programming experience, with a comprehensive simulation facility which he can use with little instruction to supplement his knowledge of the normal symbols, conventions and graphical properties of electrical network theory." (Roberts, 1965, p. 216).

"The MIT researchers plan to extend the technique from electronic networks to digital systems, treating logic gates as components. They will also apply it to distributed systems transmission and acoustic lines. . . .

"CAD includes a unique circuit analysis technique called circal, a computer program developed by an MIT graduate student, Charles Therrien." (Electronics **39**, No. 3, 39–40 (1966).)

"A typical use of AEDNET involves drawing the circuit diagram on the scope, typing or plotting values and characteristics of the components, and requesting calculation of the response to a specified input. At the user's request, the program displays the various network variables (currents, voltages, charges, and fluxes) as functions of time or as functions of each other. The user can at any time modify the network and ask for a recalculation and redisplay." (Evans and Katzenelson, 1967, p. 1135).

5.37 "The major use of the console system so far has been for problems requiring at some stage 'dynamic scratch pad' capabilities. Included in such problems have been printed circuit component and wiring placement, schematic circuit design, block or flow diagram design, text composing and editing . . ." (Ninke, 1965, p. 845).

5.38 "With this [Sketchpad] system a wide variety of structural transformations and agglomerative actions can be evoked extemporaneously by the designer. These include scaling, rotations, translations, contiguity assignments, insertions, replications—all possible on both the parts (separately within the whole of the drawing) and on the entire aggregate of features in the drawing." (Cheydleur, 1965, p. 174).

"Among the special facilities available for operation of the display system are provisions for displaying text, for drawing on the screen, and for rotating three-dimensional objects." (Fano, 1964, p. 15).

5.38a "The program 'package' called CALCULAID provides a convenient way to specify and execute requests for mathematical computation and manipulations. It runs entirely within the OPS–3 system. In addition to a general assignment-statement capability, such as the execution of the statement

$$X = Y + A^*(Z+5)$$

several more specific programs have been provided. These include a multiple linear or simple polynomial regression program, a solver of polynomial equations in one unknown, a count-by-interval program, and a program to rank-order a given sequence of numbers.

5.39 "CALCULAID and MAP are two more systems for using the computer as a mathematician's helper. CALCULAID is oriented toward writing programs to solve large problems with much data. It has built in FIT and REGRESSION operators, and a convenient way of specifying matrix operations. MAP has facilities for performing convolutions, Fourier transforms, and other more sophisticated analytical operations." (Teitelman, 1966, p. 15–16).

5.40 "By means of displays, the user receives immediate feedback of the results of his actions, and he is able to modify his decisions in order to obtain a system response that is most relevant to his needs." (Borko and Burnaugh, 1966, p. 1 (abstract).)

"These programs can be used singly, to perform individual tasks or they can be combined together in 'programs', where each step of the program is one of these macro operations. The system can be used either as a very large and fast 'desk calculator' or as a powerful programming device which allows simultaneous creation and execution of programs." (Wantman, 1965, p. 8).

"By providing instantaneous response and a multiplicity of input controls, the operator, on his CRT screen, is able to create and manipulate a model of his problem in the most descriptive and meaningful manner. With a graphic display, the user is given complete freedom in the presentation of his data, choosing whatever pictorial form he desires. Rich, problem-oriented, graphic languages can be tailored to each user's needs, allowing full statements to be made with the flick of a light pen. Concepts can be depicted in entirely new ways.

366-108 O - 70 - 7

Data can be condensed and presented in clear understandable graphs." (Stotz, 1968, p. 13).

"Most graphic input-output systems are involved in computer-aided design—a class of environments involving a high degree of interaction between designer and problem-solving system. Computer-supported drawings are a good medium for communication between human beings and design systems because drawings are easily understood by people. The graphics problem is not so much automating the drafting process, as automating the interpretation of drawings." (McCarthy, 1967, p. 64).

". . . The engineer must be able to communicate with the computer in an interactive environment where he can:

1. Request an operation.
2. Examine his results.
3. Determine the next operation to be performed based on the previous results.

"This suggests that a problem-oriented language functions best in a time-sharing environment." (Roos, 1965, p. 425).

5.40a Two examples are: "To correct an input and to immediately signal the man in the loop for a correction or the need for a correction, is an important time saving factor. Many needless hours of 'turn around time' can be saved by finding out immediately that a transcription error exists." (Bauer, 1965, p. 18).

"A most important form of output is interim feedback, which will sharpen the focus of the question after the search has started." (Taylor, 1962, p. 393).

It is to be noted in particular that

"*A communication network that does not let the user know how long it will be before his message will be delivered to the end addressee may be theoretically oscillatory.*" (Baran, 1964, p. 7).

5.40b "The man-machine coupling problem in its full breadth is the central issue in advancing interactive-computer technology." (Mills, 1966, p. 196).

5.41 "Application of man-machine systems in support of education already promises to be among the most important in terms of future implications. From a philosophical standpoint, problems of education can be included as part of the so-called 'information explosion' problem area, since the body of information to be transferred by the education process must ultimately reflect the growth of the aggregate of human knowledge." (Mills, 1967, p. 235).

5.41a In another paper, these authors comment: "While Programmed Instruction, or PI, has been evolving for a number of years, Computer-Assist Instruction, or CAI, is a much more recent arrival. This is because the computer itself is a relatively new device and time-sharing, which makes CAI economically feasible, is only now being applied on a large scale in commercial systems." (Silvern and Silvern, 1966, p. 1651).

"The term CAI should be reserved for those particular learning situations in which a computer contains a stored instructional program designed to inform, guide, control, and test the student until a prescribed level of proficiency is reached." (Silvern and Silvern, 1966, p. 1651).

5.42 "A much older CAI system is the PLATO System, developed at the University of Illinois. In the present system, each of the 20 student stations connected to a CDC 1604 computer has an electronic keyboard for student communication with the central computer and a CRT screen for viewing information selected by the computer. This CAI system has been applied to the actual teaching of electrical engineering and nursing." (Van Dam and Michener, 1967, p. 199.)

"The purpose of the PLATO project has been to develop an automatic computer-controlled teaching system of sufficient flexibility to permit experimental evaluation of a large variety of ideas in automatic instruction including simultaneous tutoring of a large number of students in a variety of subjects." (Coordinated Science Laboratory, 1965, p. 43).

"Bitzer & Easley describe a particular automatic teaching system (PLATO) in use at the University of Illinois. The interface language of PLATO exhibits an interesting approach to the problem of smooth coupling to the problem environment (example: the student can interrupt the main instructional sequence for some special tutoring by pressing a button labeled "Help"; a button labeled "Aha!" returns him to the main sequence). Among the author's conclusions are an indication that the system is actually performing as a successful educational device and that the same system implemented on an appropriately large computer would provide this kind of teaching to as many as a thousand students simultaneously." (Mills, 1967, p. 238).

"PLATO, which stands for Programmed Logic for Automatic Teaching Operations, is another laboratory for educational research. It uses an ILLIAC computer-controlled system of slides, TV displays and student response panels for simultaneously instructing a number of students. . . . It is part of the Coordinated Science Laboratory of the University of Illinois. . . .

"In the PLATO system, the computer accepts each student's request in sequence, but because of its high speed students can be served without noticeable delay. Each student has a key set and a television set. The key set, used by the student to communicate to the central computer, has keys of two types: character keys, such as numerals, letters and other symbols; and logic keys such as "continue", "reverse", "help", "judge", and "erase". These logic keys are used by the students to proceed through the instructional material. From the student's response or from the position he has reached in the program, information is selected by the computer for display on the student's television screen. This information has two sources: (1) a

central slide-selector, and (2) an electronic blackboard. Although a single slide-selector is shared by all students, each student has independent access to any slide. Each student has an electronic blackboard on which the central computer can write characters and draw diagrams. Information unique to a student such as his answer to a question, is written on his own blackboard by the computer. The images from the slide-selector and the blackboard are superimposed on the student's television screen." (Egbert, 1963, p. 622).

5.43 "CLASS stands for Computer-Based Laboratory for Automated School Systems and is a facility developed and operated by Systems Development Corporation. The CLASS facility is not considered a prototype of a school system but is devoted rather to educational research in a system context. The laboratory permits the integration of (1) individual student automated instruction, (2) group instruction, both automated and conventional, and (3) centralized data processing for administration, guidance, and planning functions. For flexibility, the central control of the laboratory is exercised by a digital computer, the Philco 2000. Various innovations in instructional load, administrative data processing, and counseling procedure can be provided by computer program modification." (Egbert, 1963, p. 621).

5.43a "PLANIT (*P*rogramming *LAN*guage for *I*nteraction and *T*eaching) is a system employing a flexible language designed for CAI. PLANIT provides for the designer a powerful and flexible tool for entering communication material into the computer, for modifying the material, for presenting it to the user, and for prescribing the behavior of the computer as a function of the user's current response and past performance. In addition, the language is simple enough to allow a nonprogrammer to use it easily." (Feingold, 1967, p. 545).

"Materials produced via PLANIT are: Instructional sequences in statistics (aimed at students of the social sciences enrolled in a first course in statistics); spelling and vocabulary (for children three to eight years); economics (for undergraduates); introduction to computer programming (for persons having some knowledge of algebra). Agencies who have used or are using PLANIT are: System Development Corporation, Southwest Regional Laboratory, University of California at Los Angeles, University of Southern California, University of California at Irvine, United States Naval Personnel Research Activity (San Diego, California), New England Educational Data System, and Lackland Air Force Base." (Feingold, 1967, p. 551).

5.44 "The IBM 1500 Instructional System is indicative of the complexity inherent in general-purpose CAI hardware. The 1500 hardware consists of CRT display units, alphanumeric keyboards and light-pens for student input, image projectors, tape-recording units, a central processing unit (the new IBM 1130), an audio adapter for sound transmission to student stations, a station control, at least two disk units, and a printer and card reader for use by the instructor. A maximum of 32 stations can be linked to the computer for simultaneous instruction. This system has been used at the Brentwood School, in East Palo Alto, California, to present mechanized reading and mathematics (e.g., set arithmetic) to first grade classes." (Van Dam and Michener, 1967, p. 199).

"The IBM 1500 Instructional System is an experimental system for computer-assisted instruction, designed to administer individual programmed lessons to 32 students at once. Working through one or more teaching devices at his own instructional station, a student may follow a course quite different from, and independent of, lessons presented at other stations. Instructional programs stored in central files control lesson content, sequence, timing, and audio-visual medium, varying all of these according to the student's responses." (Terlet, 1967, p. 169).

5.45 "This means that a chemistry student can sit at his desk and type directions to a machine that will 'perform' chemical experiments step by step . . . The student has a viewer on his desk that shows him what would happen, for instance, if he orders potassium chlorate to be added to a solution of hydrochloric acid. If the solution turns yellow or the mixing causes an explosion, the student sees this on his viewer." (Bushnell, 1965, p. 19).

5.46 "The CAI system has the capability of collecting student data, and this can be processed and regurgitated in the form of reports to the teacher and administrator. The system can provide rates of progress, areas of difficulty, problems, unexpected responses, time to complete, adherence to schedule, attendance facts, etc." (Silvern and Silvern, 1966, p. 58).

"A cumulative record is kept of the student's performance on each of the topics. These performance measures include the student's response time, error count, and pattern of errors. If a student's performance falls below an acceptable level for a topic, the student is branched or detoured to a special set of remedial items on that topic." (Egbert, 1963, p. 621).

5.46a "A few commercial speech output devices for computers or computer controlled systems have been announced. All but one of these rely on the playback of analog audio signals under digital control of selection, switching, and sequencing. The analog recording has been both magnetic and photographic. These devices generally have individual words in uniform time slots and can provide sequencing of these words under computer control. They have been used in such applications as providing stock market quotations and telephone number change information." (Hogan, 1966, p. 92).

5.47 "The IBM 7770 audio response system furnishes spoken replies to telephone inquiries . . . The inquiry is processed by the computer against stored data. The reply is composed from a selected, prerecorded vocabulary and transmitted back to the caller as a spoken message." (Licklider, 1965, p. 102).

"In the case of the 7770 the enquirer enters a request by dialling digits which are immediately transmitted to the audio response unit and then sent to the processor. The computer processes the data, composes a coded reply, and returns the message to the 7770. This device then interprets the coded reply, selecting the appropriate words from a stored vocabulary of between 32 and 128 words, and tells the enquirer the answer to his query." ("IBM System/360", 1965, p. 299).

"The 7772 . . . generates audio on the 'vocoder' principle—that of energizing tone filters and combining the output result first to form words and then sentences . . ." (Urquhart, 1965, p. 857). Knauft et al. (1966) describe further developments with respect to the 7772 audio response unit involving hardware and software features for treatment of unvoiced components of coded speech signals.

"The 7772 can have a vocabulary of several thousand words, stored on a disc device in digital form. The audio response unit recreates the spoken voice from these digital records." ("IBM System/360", 1965, p. 299).

5.48 Vocoder techniques, which were initially described by Dudley in 1936, involve devices designed to compress "the bandwidth of speech signals in order to transmit them over channels of very limited capacity. The vocoder measures the speech power in a number of frequency bands and transmits these measures as signals over a set of narrow low-frequency channels . . . At the receiver the speech is reconstituted by modulating the spectrum of a broad band source in accordance with the frequency region and amplitude of each of the measure-signals derived from the original speech. Normally this reconstituted speech signal is presented acoustically for a listener. Alternatively, vocoded speech signals can be presented visually or tactually." (Pickett, 1963, p. 2).

An alternative to the vocoder approach, also investigated by IBM, involves the development of a library of analog synthesizer control signals corresponding to subword segments of speech. Thus, "segments of control signals can be made which correspond to segments of synthetic speech, and a library of speech segments can then be stored in the form of a library of synthesizer control-function segments. The synthesizer may then be controlled by composite functions assembled from the sequence of control-function segments corresponding to the desired utterance. In order to investigate this approach to speech synthesis, a terminal analog synthesizer and associated control system have been constructed. Our goal is to generate a library of reproducible control-function segments from which we can construct connected speech." (Estes et al., 1964, p. 2–3).

5.48a It is to be noted that both the IBM 7770 and 7772 units are available in languages other than English (Urquhart, 1965, p. 857).

"Of particular advantage is that the technique is language independent, and if so desired, more than one language might be used within the same system at the same time. In the United States this is not a major problem but in Canada and in some European countries where people are often times multilingual, it is only right to assume that one should have a computer that would be too. Such a device is the IBM 7772 Audio Response Unit." (McDonald, 1966, p. 54).

5.49 "Cognitronic's 'Speechmaker' audio response units also have a fixed vocabulary of words selected and combined by computer command. These units have a maximum vocabulary of 189 words. Each word is 1.6 seconds long and is prerecorded, by a technique similar to that used to produce a sound track for a motion picutre, on a cylinder of photographic film mounted on a drum in the response unit. A narrow light beam, directed through the sound tracks on the rotating drum, is modulated by the prerecorded audio on each track and is detected by photocells. The output of the photocells is amplified and fed directly to telephone lines. This system is in use at the American Stock Exchange, enabling stockbrokers to dial four-digit codes on their office telephones and receive stock quotations; it can answer 1200 telephone inquiries in a minute." (Van Dam and Michener, 1967, p. 193).

5.50 "RCA announced that it has developed a new voice response unit . . . [providing] vocal replies to queries fed into the computer by telephone from up to 100 remote points. It is designed to work with the Spectra 70/35, 45 and 55." (Commun. ACM **9**, 468 (1966).)

5.50a "Burroughs Corporation has announced a data communications system which uses computer-stored information to generate a spoken reply through a telephone hand set . . . The voice response generator's memory is a rotating, cylindrical, photographic film containing 64 parallel tracks on which numbers, words, phrases, and silence are recorded. Photoelectric cells read the 64 tracks as they pass by, and words or numbers are selected, as instructed by the computer program, in the proper sequence to compose a message. One track is silent and provides timing and pauses desired in messages. The other 63 tracks can contain three words or numbers, each of one-half second duration or a phrase up to one and one-half seconds long. The 63 tracks, segmented into thirds, can contain a maximum of 189 individual words and numbers." (Commun. ACM **11**, No. 4, 289 (Apr. 1968).)

5.51 "Audio equipment enabling a computer to talk to students has been delivered to Stanford University by Westinghouse Electric Corporation, US. It uses a Prodac 50 computer that controls a battery of 12 random access magnetic tape units on which verbal information is recorded." (Electronics Weekly, No. 258, 8/11/65, p. 11).

5.51a "The RADC Information Processing Laboratory has sponsored research on a digital to analog converter technique for speech. A breadboard model demonstrated feasibility of converting digital information into spoken words using optical sound-

track techniques and using a vocabulary of 385 words." (Shiner, 1962, p. 338).

5.52 "Pushbutton input and audio response can be combined in the home use of computers. IBM is now experimenting with the student use of computers for homework problems, using home telephones to link to a 1710 computer; spoken answers are generated by a 7770 response unit." (Van Dam and Michener, 1967, p. 193).

5.53 "A typical dial access medical tape recording library is in operation today at the University of Wisconsin Medical School. Staff physicians record four-to-six minute commentaries on current information having to do with various subjects or procedures. The list of subjects is circulated by mail to physicians in the state. A practising physician may telephone . . . at any time of day or night and request that a particular tape be played." (Becker, 1967, p. 8).

5.54 "The Bankers Trust Company noted both favorable response and rapid adjustment of bank personnel and the public to its audio response installation." (Swanson, 1967, p. 38).

5.55 "Audio-response techniques are being used at the Space Division of North American Aviation for engineering-design status information on NASA's Apollo and Saturn projects. In this case, the words in the audio vocabulary are the appropriate ones to provide information about engineering drawings and specifications." , (Whiteman, 1966, p. 67).

"Another system is EDICT, which the space and information systems division of North American Rockwell uses to provide the company's engineers with design data. Data from more than 75,000 engineering drawings is available from any of the company's 42,000 telephones via an IBM 7770." (Berul, 1968, p. 29).

5.55a "The ability of a computer to generate answers in audible words makes it possible to obtain a great deal of information in a form understood by anyone and with the use of unsophisticated and therefore inexpensive terminal equipment. A number of computer companies have designed inquiry devices. Telephones which use tones for dialing can also be employed for this purpose by using the pushbutton tone dial after the call is established to submit the inquiry. In this case, the answer is heard in the telephone receiver." (Gentle, 1965, p. 86).

5.55b "It has been estimated that the information content of the digital voice signal is as low as 50 bits per second. Direct digital encoding of an analog speech signal by sampling, quantizing, or pulse code modulation techniques requires a bandwidth of 56,000 bps. With fixed channel vocoding techniques, the bit rate required to transmit . . . [speech] in digital form with adequate scores on intelligibility, articulation, and speaker recognition tests, has been reduced to 2,400 bps. There are other vocoding techniques which will eventually reduce this bandwidth still further to 1,200 bps, and even to 300 bps but with markedly reduced quality." (Franco et al., 1965, p. 131).

"Fairly good quality speech can be produced using about 48,000 bits per second. Even with the vast economical digital storages available today, the bit storage (using the minimum acceptable sample rate and resolution) for a 1000 word vocabulary is not particularly attractive. . . .

"Certain economies of storage can be achieved by the use of the channel vocoder mainly because of the redundancy of human speech. That is to say, every instant of speech is not a wholly new complex waveform but is generally the repetition of the same complex wave form a number of times and then changing to another. By taking advantage of this unique quality of speech, it is possible to digitize a portion of speech, a word, inspect it for its redundant aspects and rather than store all of the redundancy, establish a count of the number of times a given pattern is used before it changes to another pattern. . . .

"By the use of this technique it is possible to store reconstructable digitized speech so that approximately twenty-four hundred bits represent one second of speech [one to two words]. This is a considerable saving in space over the minimal 24,000 bits and the desirable 48,000 bits." (McDonald, 1966, p. 53).

5.56 Under the general direction of G. Fant (1959), the work of J. Liljencrantz, U. Ringman, P. Tjernlund and others of the Vocoder Group, Speech Transmission Laboratory, R.I.T., is primarily concerned with speech analysis and speech synthesis. Both a speech analyzer and a speech synthesizer are in operation can be used together to improve the vocoding performance. A new spectrum analyzer has been designed for on-line operation with a computer, including such tasks as varying formant and anti-formant information, i.e., to take samples of natural speech, to extract parameters, and to try to replicate them with the speech synthesizer. (See Stevens, 1968).

5.56a "A speech synthesis program was written at Manchester (Mathers, 1964) based on the Parametric Artificial Talker at Edinburgh University (Anthony and Lawrence, 1962). The eight parameters required by this program were measures of the frequency of relatively dense energy bands in the spectrum, energy amplitude measurements, and measurement of the fundamental frequency of the waveform. Two other synthesis programs were developed which required nine and eleven parameters, representing a closer description of the spectrum. Three analysis programs were written which automatically measured the spectrum and produced the appropriate parameters from the speech waveform." (Lavington and Rosenthal, 1967, p. 338).

"Routines r6 and r7 were developed for use in a system of automatic speech analysis and synthesis (Rosenthal, 1965). This system was based on the assumption that the intelligible information in

speech may be expressed as values of a few slowly varying parameters, and that these parameters may be measurements of characteristics in the spectrum of the speech waveform. The object of the exercise was to obtain a reduction in the data rate of speech transmission without loss of information. It was desired to produce analysis programs which would form the spectrum of the speech waveform and measure the values of several parameters which would then be used as input to a synthesis program. The synthesis program would produce a waveform whose spectral characteristics were controlled by the parameters, and which would hopefully, be judged similar to the original by human listeners." (Lavington and Rosenthal, 1967, p. 338).

5.57 "A voice-excited vocoder has been successfully simulated on the IBM 7094 computer and satisfactory quality of voice has been reconstructed with 220–660 cps frequency used as the voice-excitation band. Experiments are under way to convert the vocoder output to a binary data stream and investigate the effect of channel coding techniques on the reconstructed voice." (Quarterly Progress Report No. 80, Research Laboratory for Electronics, M.I.T., 179 (1966).)

"The general research problem of artificial speech generation is under continuing investigation in Professor K. N. Stevens' Speech Communications Group and particular application to the reading-machine system is being considered in cooperation with his group." (Quarterly Progress Report No. 80, Research Laboratory for Electronics, M.I.T., 218 (1966).)

5.58 "Study of the speech process is interesting in its own right. It is, moreover, a route to practical applications, not only in the engineering of devices for speech recognition, bandwidth compression, and prosthetic aids to the blind or deaf, but also to the more common problems that arise in connection with the use of language by normal and handicapped people. The research on speech has necessarily been interdisciplinary, requiring close working cooperation among linguists, experimental psychologists, and engineers." (Cooper, 1967, p. 1214).

5.59 "An interesting application of audio output is the work at MIT's Research Laboratory of Electronics to develop a 'reading' system for the blind that will read printed English text aloud. The project is divided into three phases: recognition of characters; translation of words into 'phonemes,' the minimum units of speech; and conversion of the phonemes into speech, using a speech synthesizer. To date, phases one and three have been completed. These modules have been built at the Laboratory and have cost only a few thousand dollars, since special high-speed equipment was necessary. The character recognizer uses TX–O and PDP–1 computers to perform the recognition. It can now scan printed input, recognize each letter, and output the character vocally. The overall reading rates arc about 60 to 80 words a minute, with a high degree of accuracy." (Van Dam and Michener, 1967, p. 194).

5.59a "It should be clear that with the addition of a printer character-recognition unit, the system is useful as a reading machine for the blind. It was originally with this purpose that our research into computer generation of connected speech from text source began." (Lee, 1968, p. 333).

5.59a2 "Formant amplitudes have not been studied much in previous investigations Formant frequencies and over-all intensities have received much more attention. . . . A correct reproduction of formant amplitudes in synthesis is necessary for ensuring one of the elements of naturalness, such as, for instance, a voice source of correct spectrum shape." (Fant et al., 1963, p. 1760).

5.59a3 "It is a mistake to suppose that, once vowels and consonants have been simulated in isolation, their conjunction will result in intelligible speech. If the formants are varied in a stepwise fashion, the resulting sounds are quite unintelligible unless one knows what was intended beforehand. In natural speech, the formants vary slowly and smoothly, even persisting through seemingly colourless sounds like 'sh', where they form a smooth interpolation between the preceding and succeeding values occurring in the speech. But with sufficiently fast machines, all these things could be allowed for by program." (Woodward, 1966, p. 262).

"Perhaps the intonation of the voice will be the most resistant problem; we have no notation for its inflexion and little understanding of the rules by which inflexion conveys meaning. This, it may be suggested, is why computer voices are often programmed to sing rather than to speak." (Woodward, 1966, p. 262).

5.59b "The resulting speech is usually intelligible, but not suitable for long-term use. Several problems remain, apart from those concerned directly with speech synthesis by rule from phonemic specifications. First, many words can be nouns or verbs, depending on context [refuse, incline, survey], and proper stress cannot be specified until the intended syntactic form class is known. Second, punctuation and phrase boundaries may be used to specify pauses that help to make the complete sentence understandable. Third, more complicated stress contours over phrases can be specified which facilitate sentence perception. Finally, intonation contours, or 'tunes' are important for designating statements, questions, exclamations, and continuing or terminal juncture. These features (stress, intonation, and pauses) comprise the main prosodic or suprasegmental features of speech." (Allen, 1968, p. 339).

5.59c "The parser makes two passes (left-to-right) over a given input sentence. The first pass computes a tentative bracketing of noun phrases and prepositional phrases. Inasmuch as this initial bracketing makes no clause-level checks and does not directly examine the frequently occurring noun/verb ambiguities, it is followed by a special routine

designed to resolve these ambiguities by means of local context and grammatical number agreement tests. These last tests are also designed to resolve noun/verb ambiguities that do not occur in bracketed phrases, as [refuse] in [They refuse to leave.]. As a result of these two passes, a limited phrase bracketing of the sentence is obtained, and some ambiguous words have been assigned a unique part of speech, yet several words remain as unbracketed constituents." (Allen, 1968, p. 341).

5.59d "Another possible approach is to use partial words as the the basic unit to be stored. Research in this area has been very limited. Stowe and Hampton have constructed connected speech from syllables and have reported intelligibility scores of 90 per cent when the speech was produced at the relatively slow rate of 2 words per second. When the rate was increased to a more natural 4 words per second intelligibility dropped to 66 per cent. Harris attempted to construct speech by using the basic sound of English as his stored units; that is he stored (in analog form) sounds representing P, T, A, and so on, these having been cut from words in which these sounds occur. Since it has been long recognized that production and perception of sounds are affected by adjacent sounds, it was necessary in his method to have several representatives of many of the sounds. That is, a different kind of O might be necessary if it were to follow a T than if it were to follow a K, and so on. Using a small inventory of such sounds, plus rather elaborate analog equipment for synthesizing monosyllables from the stored sounds. Harris obtained approximately 75 per cent intelligibility.

"An approach somewhere between the use of single sounds and the use of syllables is the use of dyads that approximately represent the last half of one sound and the first half of a following sound. The advantages of dyads are that they include the natural transitions of speech from sound to sound, while still keeping the required inventory to a manageable size. Wang and Peterson, on theoretical grounds, have calculated that an infinitely large message set could be produced using approximately 800 dyads for monothonic speech and approximately 8500 dyads for intonated speech. Assuming that a dyad lasts for 50 to 100 ms, it can be seen that even using high-quality PCM coding of the waveforms, an 800-dyad inventory would require only about 5,000,000 bits of storage . . .

"The decision to use natural rather than synthetic speech to obtain our dyad inventory necessitated the development of a system to extract portions of a speech waveform and store them for later recall. It was necessary to isolate segments of speech as short in duration as 40 ms. Splicing speech segments to this degree of precision was accomplished using a research tool developed at the Sensory Science Research Center. A CDC-3100 computer, coupled to a high-performance, interactive display system, has been programmed to provide a visual display of a previously digitized speech signal . . .

"The speech signal being displayed is cut in the same manner that it would be for splicing. However, in this case the portion of the waveform between the 'cuts' is played back to the operator on head phones. The selected portion may be played back a single time, or (under operator control) it may be joined to itself and repeated continuously as many times as desired. This feature is particularly useful for listening to repeated versions of single periods in voiced speech which can be used to determine boundaries of voiced dyads.

"Finally, a word should be said about the problem of intonation. In this experiment, we have not attempted to produce any prosodic features. This problem could be handled in two different ways. First rules could be developed for modulating the pitch, amplitude, and duration of the stored dyads, according to the intonation needed in a given message. These rules would presumably be similar to those being developed in various speech model synthesis systems. Secondly, the dyad inventory could be expanded to include several representatives of each of the dyads, some with rising inflection, some with steady high pitch, etc. Wang and Peterson have calculated approximately 8500 segments would be required to represent all of the inflections used in English. Although this would greatly expand the work required to construct a dyad system, the technique is relatively straightforward and might be justified in the case of a user who needed very high-quality, natural speech." (Becker and Poza, 1968 p. 795–800) References are to Stowe and Hampton (1961), Harris (1953), and Wang and Peterson (1958).

5.59e In this connection, Dolby et al. point out that "solutions to the affix and syllable-counting problems are essential to the determination of an algorithm for transcribing written English into any of the standard phonetic transcription systems now in use." (Dolby et al., 1965, pp. 1–15).

5.59f "Speech synthesis by rule is the method of converting from a discrete representation of speech in linguistic units, that is, phonemes and stress marks, to a continuous acoustic waveform . . . The discrete input is converted to continuous control signals by the synthesis strategy. The synthesis strategy contains stored information about the phonemes and stored rules about the mutual effects of adjacent phonemes. The stored rules operate on the input sequence to produce the control signals for the synthesizer. The speech synthesizer converts the control signals to continuous speech. The synthesizer may be a terminal analog, a dynamic analog of the vocal tract, or a combination. . . .

"Each phoneme has a characterization independent of adjacent phonemes. The characterization includes format information, source characteristics in the production of the phoneme, a description of whether it is nasal or fricative, and a set of frequency regions surrounding the formant positions.

"The formant information is a set of target positions for both center frequency and bandwidth of

formants one, two and three. The source characteristics describe the condition of the vocal cords during the production of the phoneme. If the vocal cords are vibrating the sound is voiced. The frequency regions of a phoneme represent the degree to which certain acoustic parameters must approximate the target values of these parameters in the context of connected speech. In an articulatory analog, the corresponding concept would be the extent to which a given vocal tract configuration must approximate the target configuration for the phoneme . . .

"For certain consonants maximum durations are specified. Consonant duration (as measured from human speech) is not a fixed quantity but is very dependent on context. (For example, initial consonants are much longer than medial consonants.) The synthesis strategy generates consonants whose duration is variable within certain limits. Maximum durations are specified to prevent the consonant from being unnaturally long, hence objectionable. . . .

"Among the topics that will be considered for future work are the effects of stress and rhythm on timing of an utterance, the inclusion of more than one breath-group in an utterance, and studies of further correlates of word boundaries." (Rabiner, 1968, pp. 17, 23–24, 36).

5.59g See Lee (1968). In summary,

"F. F. Lee of the Cognitive Information Processing Group has concluded that the technical advance in low-cost high-density read-only storage has made it feasible to consider the imitation of the human reading habit by machine and is now developing a scheme for automatic translation of English text from letters to phonemes. Specifically, a lexicon containing on the order of 32,000 selected morphemes and words can be used together with algorithms to give phonemic translation for a vocabulary equivalent to what is contained in the Webster New Collegiate Dictionary." (Cornew, 1968, pp. 88–89).

5.60 "Spelled speech offers a slower but simpler auditory display than artificial speech. Under consideration are magnetic and optical storage and read-out of the spoken-letter sounds, and under investigation is the compression of spelled speech by sampling in sections, temporal truncation, and temporal-overlap superposition. . . .

"Errors in phonetic spelling, arising from erroneous character recognition and resulting in phonetic nonwords, can be accommodated by spelled-speech display of the erroneous English word. Spelled speech is also a reasonable possibility for phonetically intractable proper names." (Quarterly Progress Report No. 80, Research Laboratory for Electronics, M.I.T., 219 (1966).)

5.60a "The work reported here was concerned with what we might call the pianola problem, that is to say, the use of the computer to reproduce a sequence of predetermined sounds from a previously handwritten 'score' without the use of specialized peripheral equipment or analogue devices. A good tune was, to the best of the author's knowledge, first played on the Ferranti Mark I computer at Manchester, with Mr. C. Strachey at the controls. Nowadays, with faster computers, it is possible to play several good tunes at the same time. S. N. Higgins produced a common chord from a computer (TREAC) by time-multiplexing as long ago as 1954. The compilation of the necessary instructions made a more startling sound than the climatic chord itself." (Woodward, 1966, p. 257).

"As the preparation of the tape for a piece of music can be most time-consuming and the final performance is of little serious value, the effort is unrewarding unless a suitably convenient code is devised. The code should allow the use of variable-length notes referred to a diatonic scale modifiable by sharps, flats and naturals. Rests can be input as notes of zero frequency. The score is best stored in its entirety with all variables ready converted into the form needed by the program at runtime. During play, a pitch transition in any one part necessitates resetting a pitch constant in the program, and as the various parts have unrelated audio phases, no time for such resetting can be found without interrupting the other parts. If all the other parts move at the same time, the break is insufficiently long to destroy a legato effect, but if one part is tied, its continuity is spoiled unless the resetting computation is carefully timed and short enough not to interrupt it. The author has found it necessary to draw the line before incorporating this last refinement, which is only the first of what could easily become an evermore demanding pastime." (Woodward, 1966, p. 261).

5.60b "At present, the generation of sound by computer affords the researcher and composer at least three interesting possibilities: (1) experiments in auditory perception—characterized by Babbitt as 'the most refractory of areas', (2) the study of musical 'grammars', (3) the development of original compositions. The greatest amount of activity has occurred in the latter category. Early credits go to Max Mathews and the MUSIC IV program for sound-generation and to Lejaren Hiller at the University of Illinois. More recently, computer generation has been carried out at Princeton (by James Randall, Godfrey Winham, Hubert Howe, and others), at Yale (by James Tenney), and at M.I.T. (by Ercolino Ferretti and by A. Wayne Slawson)." (Forte, 1967, p. 328).

Forte suggests further that "computer-generated graphic displays offer new resources for the editing procedures that are central to much work in musicology" (1967, p. 329).

5.60c "Experiments at Stanford University, Stanford, Calif., indicate that a computer fitted with a special device can be used to teach pitch to singers. Prof. Wolfgang Kuhn of Stanford's Music Department, writing in the fall issue of The Journal of Research in Music Education, reported favorable results with an experimental 'pitch extraction device'. The device was developed

as a laboratory research tool by two IBM engineers, Jerome D. Harr and Bruce Moncreiff, for use with IBM's 1620 computer at the company's Los Gatos Advanced Systems Development Division.

"The computer is programmed to evaluate a series of musical tones by comparing a student's pitch to the true pitch. It can distinguish between male and female voices, which it translates as 'high' or 'low'. It also can detect deviations from perfect pitch from as much as four per cent to as little as half a per cent. When a student is ready to practice with the computer, a tape-recorder can offer him a sample pitch or he may play a series of notes on an organ-like keyboard which produces a true tone. Then he sings into a microphone the tones which the computer has printed out to the beat of a metronome.

"Prof. Kuhn programmed a series of sight-singing exercises together with tests and options into the computer's memory with the help of his assistant, Raymond Allvin. He used 10 under-graduate music students from San Jose State College. They were instructed in the use of the machine, and given a standard musical achievement test. Then they went through a three-hour period on the machine, spread over a three-week period, after which they were again tested against the same (Aliferis) achievement test.

"The students noted an increased, awareness of pitch and accepted the machine's criteria of perfect pitch. Prof. Kuhn said IBM's pitch-extraction device worked well: only once in 10,000 tries did it give an erroneous report. 'Each note in the performance was sampled', Prof. Kuhn reports, 'and the pitch analyzed. The computer decided whether a specific exercise was to be repeated, or whether the student should go forward in the program or repeat similar material for more practice.' Each student's records of performance are collected and stored in the computer memory so that his progress can be accurately measured and help given where needed.

"Prof. Kuhn, who used a small Music Department allocation for his study, foresees the day when a complete curricula in melodic, rhythmic and harmonic sight-singing and dictation could be computerized and adapted for any level of musical development. He also envisions instructional systems for learning to play instruments." (Computers and Automation **16**, 61 (Dec. 1967).)

5.60d "The display can also represent a three-dimensional object which can be automatically rotated around any given axis keeping the drawing in proper perspective as it rotates. The ability to display a three-dimensional perspective drawing and rotate this drawing to show the view from other vantage points is particularly interesting in architectural design. . . ." (Hobbs, 1966, p. 1873).

5.61 "Levinthal has recently started to develop a system for sequentially displaying two-dimensional images of a protein molecule, to provide an apparent three-dimensional molecular model on the face of an oscilloscope tube. This work is apparently extendible to a wide range of structural representations. Consideration of the problems associated with storing, interlinking, retrieving, and translating the data to compose a three-dimensional model on the scope provides an intriguing view of data-handling capability that will be required in the future. How widely such a technique will be useful depends upon the availability of required data in the literature, but if the techniques of retrieving and manipulating the data are not developed, the data are apt never to be generated and used." (Tate, 1967, p. 295).

"We . . . decided to develop programs that would make use of a man-computer combination to do a kind of model-building that neither a man nor a computer could accomplish alone. This approach implies that one must be able to obtain information from the computer and introduce changes in the way the program is running in a span of time that is appropriate to human operation. This in turn suggests that the output of the computer must be presented not in numbers but in visual form . . .

"In working with molecular models we are interested in being able to obtain data quickly in order to evaluate the effect of changing the input variables of the program . . . We realized that our best hope of gaining insight into unexpected structural relationships—relations that had not been anticipated—lay in getting the computer to present a three-dimensional picture of the molecule . . ." (Levinthal, 1966, pp. 49–50).

"During the last year we have written a set of programs which allows the construction, the display, and the analysis of macromolecules using a digital computer and an oscilloscope display. With this computer controlled display and real time rotation of the projection of the molecule being displayed, it is possible for the observer to obtain a true three-dimensional visualization of the molecule. . . .

"Since even a small protein molecule may contain 1500 atoms, the total number of pairs to be tested is very large. In order to avoid the enumeration of all possible pairs, a set of programs has been written which divides space into cubes and then makes a list of all atoms in each cube. In this way it is possible to enumerate all pairs of neighboring atoms by searching through the cubes and listing those pairs in which one member is in a cube and a second member is in the same cube or one in the 26 surrounding ones. By using this list processing procedure it is also possible to define 'holes' in a molecule by locating empty cubes surrounded by filled ones. In addition, 'insidedness' and 'outsidedness' of the molecule can be determined by finding cubes which have filled neighbors on one side and empty neighbors on the other side. The knowledge of these aspects of the topology of a folded protein are necessary in order to evaluate the contributions resulting from the interaction of particular amino acid residues with the water which

normally surrounds all protein molecules." (Levinthal, 1966, pp. 315, 317).

"It is still too early to evaluate the usefulness of the man-computer combination in solving real problems of molecular biology. It does seem likely, however, that only with this combination can the investigator use his 'chemical insight' in an effective way. We already know that we can use the computer to build and display models of large molecules and that this procedure can be very useful in helping us to understand how such molecules function." (Levinthal, 1966, p. 52).

5.62 "Multipurpose three-dimensional graphs can now be produced from electronic data processing equipment with a newly developed spatial data plotter announced by Spatial Data Systems, Inc. . . . X- and Y-dimensions on the flat bed of the plotter are represented by the position of a series of metal pins thrust upward through the board's surface; the Z-dimension is pin height. All pins are step-motor positioned." (Commun. ACM **10**, 253 (1967).)

5.63 Some illustrative notes and comments on three-dimensional data input, from an earlier report in this series, are summarized as follows: Stereoscopic initial data recording and three-dimensional data depth reconstruction by machine processing and computational techniques are of significance in such areas of information processing system application as aerial photograph interpretation, map or contour matching, and analysis of bubble-chamber data. For example, a scanner developed by Moore et al. (1964), digitizes 9″ aerial photographs for computer analysis of stereographic differences.

R & D interests in the area of three-dimensional data input and manipulation are exemplified first by the Sketchpad III system at M.I.T., which is a computer program to facilitate entry and processing of three-dimensional drawings (Johnson, 1963). Roberts reports that: "After a list of three-dimensional objects has been obtained in some manner, it should be possible to display them from any point of view . . . The three-dimensional display program will do all this and more." (Roberts, 1965, p. 185). Fano comments further that "special equipment developed by the Electronic Systems Laboratory at M.I.T. makes it possible to draw with the light-pen a three-dimensional object and display its projection on the face of the cathode-ray tube just as if the object were continuously rotating in three dimensions under the control of the viewer." (1967, p. 31).

An idealized graphic input-output system, to be capable of processing "three-dimensional curve and surface projections", is reported by Parker (1965). Developments in new technologies, such as those of holography, offer additional possibilities for three-dimensional data processing, storage, and retrieval.

A more recent example of practical 3–D data processing applications has been reported as follows: "A computer at Brown University (Providence, R.I.) is creating pictures—as simple as a cube and as complex as a refinery pipeline—that can be seen in three dimensions. The 3D project has been undertaken by Charles M. Strauss, a graduate student, and Dr. Andries van Dam, assistant professor of applied mathematics, who is supervising this doctorate work in the Division of Applied Mathematics.

"Mr. Strauss has created a program for the university's System/360 Model 50 which enables the computer to construct a pair of images, differing slightly in perspective, side by side on a television-like screen. When viewed through the stereoscope mounted in front of the IBM 2250 display screen, a person sees the two images merged into one with the added dimension of depth.

"The images, geometric models stored in the computer's memory, can be manipulated on the screen—enlarged, reduced, moved up or down or rotated—by pressing various keys on the display unit. In addition, a person can draw or alter the pictures generated by the computer through the use of a light pen." (Computers and Automation **16**, No. 11, 52 (Nov. 1967).)

In addition, we note that "an experimental pseudo 3–D display at the White Sands Missile Range was reported to incorporate several 3–D cues, including perspective, shadow patterns and color." (Vlahos, 1965, p. 15).

5.64 A recent example is summarized as follows: "A perspective transformation is developed whereby an object in space as viewed from an arbitrary point can be projected into a plane and plotted . . . An algorithm which eliminates the plotting of hidden portions of the object is discussed." (Kubert et al., 1968, p. 193). For earlier examples and discussion see the first report in the present series.

5.64a "There are . . . considerable reasons for developing techniques by which line drawings of solids can be shaded, especially the enhancement of the sense of solidity and depth . . . Shading can specify the tone or color of a surface and the amount of light falling upon that surface from one or more light sources. Shadows when sharply defined tend to suggest another viewpoint and improved surface definition. When controlled, shading can also emphasize particular parts of the drawing. If techniques for the automatic determination of chiaroscuro with good resolution should prove to be competitive with line drawings, and this is a possibility, machine generated photographs might replace line drawings as the principal mode of graphical communication in engineering and architecture." (Appel, 1968, p. 37).

5.65 "The examples given in the preceding paragraphs are representative only of a few of the many provocative visual presentations using depth made possible by the computer technique described in this article. The most obvious use is in the presentation of curves and functions of three variables. When visualized in true depth, many important trends in data become quite evident, as

for example, the formant structure of the speech spectra. . . . Here is a method for presenting stress diagrams, the construction of beams and bridges, the structure of molecules, functions of a complex variable, and much more—all viewed from any angle and any distance. It is apparent that further applications are limited by only the imagination of the prospective user." (Noll, 1966, p. 156).

"The present system definitely proves the feasibility of the real-time display of two-dimensional half-tone images. It is felt that the technique may be easily extended to stereo representation of half-tone images. Furthermore, the algorithm is so constructed as to allow computations to be executed in parallel (see the dotted section in Figure 11). As many scan lines as hardware permits may be calculated simultaneously. Also, much of the computation may be performed by incremental hardware. The parallel and incremental characteristics of the algorithm lead us to believe that real-time movement and display of half-tone images is very near realization." (Wylie et al., 1967, p. 58).

5.66 "A researcher at the Mitre Corp. . . . has developed a technique to make a three-dimensional display with mirrors and an off-the-shelf loudspeaker . . . As the flexible mirror vibrates, becoming alternately concave and convex under the influence of the speaker's pneumatic drive, the change in curvature causes a reflected image vibration also . . . One of the potential applications is in air traffic control for displaying air space in three dimensions, range, azimuth and elevation." (Electronics **39**, No. 3, 41–42 (1966).)

5.66a "Utah computer researchers create 'Idea Photographs'. Researchers at the University of Utah are using a computer to create three-dimenional, halftone 'photographs' of a man's ideas. The research opens the door to a large area of creative visual electronics, with remarkable possibilities in nearly every field from entertainment and education to architecture and medicine.

"The group of scientists working on the project has made 'photographs' of objects that exist only in the minds of those at the computer controls. The photograph-like reproductions were 'materialized' by the computer, which had been previously programmed in the mathematics appropriate to light and shape.

"This development opens up many future possibilities such as:

1. Motion pictures in three dimension which give the illusion of live action;
2. Computerized architecture, which would allow the designer to spend ninety percent of his time on creative work; this would include three-dimensional building design, eliminating the need for blueprints in the design process, and allowing the designer to show viewers (through a special set of 'goggles') how the structure will look on the site; and
3. Realistic visual aids which will modify teaching methods in education.

"The scientists are working under a four-year, $5 million contract with the Advanced Research Projects Agency, Department of Defense, Washington, D.C., to increase communications and graphic techniques between man and computers.

"In the halftone research, which is part of the project, the group is working initially with geometric shapes, like cubes, pyramids, and spheres. These building blocks, once they are programmed into the computer, are 'stretchable' and can be manipulated into many different combinations of design forms and shapes.

"One of the practical applications of halftone research may come in the field of architecture. The new computer graphics should allow an architect to design a building on a large cathode-ray tube instead of a drawing board. He will need to do so only once, and he will be able to do so in perspective, right down to the last detail. In the process, the computer can rotate the design for a view from any angle. The architect can magnify any section for close-up examination, and can remove walls to look inside any part of the structure." (Computers and Automation **17**, No. 2, 11 (Feb. 1968).)

"A computer that makes television pictures out of numbers has been developed by General Electric's Electronics Laboratory, Syracuse, N.Y. This computer, designed for NASA's Manned Spacecraft Center in Houston, Texas, will be a part of NASA's simulation facility.

"The purpose of the computer is to generate life-like TV pictures of objects such as NASA's Lunar Module, Command & Service Modules and the lunar surface. The computer creates pictures of these objects from numbers stored in its memory—numbers that mathematically describe the shapes and colors of the objects. There are no TV cameras, no films or slides, and no models or drawings in the system.

"The numbers that describe a particular scene are on tapes which are read into the computer's memory initially and remain there until deliberately erased or until a new tape is read in. Since the 'models' are only computer tapes, it is possible to change from one simulation task to another in a matter of seconds.

"The operator can see the computer's visualization from any vantage point. In effect, he enters the computer's world by manipulating an aircraft-type control stick. The computer senses his location through the movements of the control stick, then computes and presents a TV picture of the scene as it would appear for an instant in time. This process is repeated up to thirty times per second, giving the operator the same visual sensations he experiences in a 'real-world' situation.

"In addition to space objects and scenes, the computer has been programmed to create pictures of an aircraft carrier, an aircraft, an airport, and a street scene . . . The computer is given a series of numbers that tell it the shape and colors of the airport. From the numbers fed to its memory, the

computer draws the airport on a TV screen. As the viewer manipulates the aircraft-type control stick to inform the computer where he would like to be in relation to the airport, the computer re-computes the exact perspective and size of the scene for the viewer's location." (Computers and Automation **16,** No. 11, 53 (Nov. 1967).)

5.67 "Dr. Nathan [Jet Propulsion Lab.] says that he has been able to use the computer to draw three-dimensional contour maps of the lunar surface. The 7094 accomplishes this by comparing light and dark areas in lunar pictures and computing the angle of slopes and relative roughness and elevations between them." (The Computer Bull. **9,** 62 (1965).)

5.67a "This paper describes Design Language I (DLI)—a prototype computer-aided design system. DLI addresses the creative design of 3-dimensional structure, using a display console for communication with the user. . . .

"The prototype DLI system handles design of 3-dimensional objects consisting of points, straight lines, and planes. Additional elements are scalars (holders for single numbers), sets (collections of elements), views (2-dimensional displays of elements) and modes (holders for definers to be applied to each element created when the mode is active)." (Denil, 1966, p. 527).

"Results from the prototype implementation indicate that the language modelling approach to the design problem is sound. A designer may start work by sketching a basic object using the APPNT and SKLINE nouns. Once a rough outline is obtained, the object may be modified into the desired shape with no difficulties; it is found that the process is very similar to the process one uses in sketching and then refining this sketch into a finished design." (Denil, 1966, p. 535).

5.68 "The questions of color, 3–D, and size of display are matters of continuing controversy in our service laboratories." (Rosa, 1965, p. 412).

5.69 "A technique that could permit radar or sonar screens to display hundreds of different colors has been developed by Sylvania Electronic Systems . . ." (Electronics **37,** No. 18, 18 (1964).)

5.69a "It is necessary to make compromises in some characteristics in order to accept a display technology that meets other essential requirements more important to the particular application. A decision as to whether to use a multi-color system in a large-screen display is an example of the compromises that must be made. The use of several colors in a display offers definite advantages in terms of the ability to distinguish different types of items (e.g., in a simple case, friendly and hostile forces); hence, from the user standpoint a multi-color system is desirable. However, a color display usually involves a significantly greater amount of equipment and hardware which implies an increase in space and cost (and probably adverse effects on reliability and maintainability). Hence, the systems designer must balance the need for multi-color displays from the user standpoint against the penalties that may result in other performance characteristics, in cost and size, and in reliability." (Hobbs, 1966, p. 1877).

5.69b "Current [command and control] systems call for displays that can handle large volumes of data in real time and that are bright, in full color, of high resolution, and highly flexible. There are no existing displays that can provide this total capability. New techniques must be provided to ensure that the display does not become the weakest link in the data-processing chain." (Baker and Rugari, 1966, p. 37).

5.69c "The technical and economic obstacles that have prevented the use of color in console displays are rapidly vanishing with the effect that at least two manufacturers (ITT and Philco-Ford) are currently producing full-color, general purpose, console displays. General Electric has also announced a small-screen color display designed for NASA.

"The Sylvania tube produces two colors using a single gun tube and two phosphors, one for each color. The color selection is performed by changing the post-deflection accelerating voltage which changes the beam energy. A high energy beam penetrates the first phosphor layer and excites the second, while a low energy beam does not penetrate thereby exciting the first layer. . . .

"One recent system, developed by General Electric, produces a full color perspective picture of an aircraft carrier deck and is used to train naval pilots. The position of the carrier is under computer control and changes according to the trainee's actions." (Mahan, 1968, pp. 20–21, 31).

5.69d "Radio Corporation of America (RCA) has modified its color scanners so they can produce four-color separations from reflection copy, as well as from colored transparencies. RCA has also announced the Graphic 70/8821 Composing Color Scanner. It has a three-part scanning cylinder. Two transparencies can be mounted on two of these, with a mask on the third. The scanning head over the mask controls the switching-over from one color transparency to the other to produce any desired composite picture.

"Crosfield Electronics, Ltd. also has a new scanner, called Diascan 2000. It scans one color at a time, with a resolution of 500, 1000, or 2000 lines per inch." (Hartsuch, 1968, p. 57).

5.70 "The hardware is based on a 7090 computer, the Stromberg-Carlson 4020 microfilm recorder, provision on the master film for designating sequence lengths for individual frames and standard optical printing.

"The programming involves a 'scanner language' which assumes 26 addressable scanners 'looking at' specified cells of a 252 x 184 image matrix, where numeric values 0–7 indicate gray scale." (Knowlton, 1964).

5.71 "To completely automate the movie process, one experiment used a General Dynamics/

Electronics SC–4020 cathode-ray tube as an electronics draftsman. This tube, with its associated circuitry, was connected directly to the computer. The different drawings were projected electronically on the face of the tube. The time of each projection was 0.035 second. These projections were then recorded on film." (Gomolak, 1964, p. 70).

5.72 "Previously, animated movies were made a single frame at a time—a time-consuming and tedious process. Now, however, special photo-optic equipment under the control of a high-speed digital computer is being used to generate animated movies. For example, such computer-generated movies have been used at the Bell Telephone Laboratories to demonstrate the effects of different gyroscope constraints on an orbiting satellite. Also, an ingenious computer-programming language has been devised for producing computer movies. . . . "The computer method for generating a three-dimensional movie is first to calculate, at some particular instant in time, the three-dimensional coordinates of the points in a line-drawing representation of the desired object. The three-dimensional movie program then calculates the points required for the two perspectives and also generates the instructions for drawing the perspectives with a plotter. The three-dimensional coordinates of the object at a small time increment later are then computed, and the three-dimensional program generates the instructions for another frame of the movie. This procedure is repeated on a frame-by-frame basis until the desired movie sequence is completed. The movie is then recorded on magnetic tape which is used as input to the plotter. The plotter decodes the instructions on the tape and repeatedly advances the film and deflects the electron beam until the entire movie is completed." (Noll, 1966, pp. 143–145).

5.72a "This paper presents a generalized technique for generation of off-line CRT motion-picture displays of objects in three-dimensional space. Initial implementation of the system, called VISTA* (Visual Information for Satellite Telemetry Analysis), uses the Univac 1108 computer to generate time-sequence displays for output on the Stromberg-Carlson 4020 microfilm plotter. The system accepts satellite orbit and attitude data and produces motion pictures illustrating the three dimensional position and orientation of the spacecraft in orbit, relative to one or more celestial bodies." (Chapman and Quann, 1967, p. 59).

5.73 "Until now the designer has been concerned with the many, detailed problems of designing and producing large, single-path information systems. Mixing presentation media into one system has been limited to the efforts of the military, notably intelligence, groups who were forced to cope with the problem of photographic intelligence and the synthesis of this and other data into indications of hostile activity . . . The total network requirement [is] for presentation technology-in-combination. . . .

"And why should we be concerned about mixing media—text, audio, pictorial—into one single information network? For two reasons: one, to accommodate the transfer of information to some users for whom one form will not suffice; two, because of the very nature of information itself, because certain types of information are communicated more effectively in visual or audible forms. . . .

"We must, therefore, consider ways to handle digital data, video, analogue and any combinations of these to best affect the transfer of knowledge from originator to user.

"The problem of mixing presentation media is extraordinarily complex if we consider the various forms that data can take and the various sub-sets of this data. The primary forms of data, for example, are original text, or the written word, audio information and pictorial data. If we draw these three forms of data as three overlapping circles, we can see that we have seven combinations of data to contend with. In medicine the written data would be the texts of authors contained in books, journals, and miscellaneous monographs. Audio data would be heart murmurs. Pictorial data would be surgical techniques. Audio data could be combined with visual demonstrations of palpations. Written data could be accompanied by diagrams or illustrations.

"Thus, we have seven combinations of data presentation to consider. Let us now look at the sub-sets of each of these. Full text can appear as abstracts of the text, as shorter indexes, as titles and paginations, or as evaluative data about the text such as reviews or comments on the content of the text. For the text set alone we, therefore, have four sub-sets of information, all or none of which may be available. All of these should be considered for the total information network." (Mayeda, 1967, pp. 4–5).

5.74 "It seems to us that there is some merit in trying to develop such large-scale, high-resolution dynamic displays for group-computer interaction, though at the same time we appreciate the difficulty of the technical problems involved." (Licklider, 1965, p. 102).

5.74a "With the ability to scan preliminary or approximate results while his problem is still on the computer, and to immediately make on-line modifications in method or detail of calculations, the user need not plan his calculations so carefully in advance, nor does he need to request fine detail over all ranges of a function simply because he cannot tell in advance where the interesting regions are." (Ward, 1967, p. 48).

See also note 5.40, pp. 91–92.

*VISTA was developed by Computer Sciences Corporation for NASA–GSFC.

6. System Output to Microform and Hard Copy

6.1 "First, the well-established tradeoffs between digital and microform technologies have changed little; both technologies have steadily improved in terms of capability and lower cost. These improvements have made equipment more accessible to the 'average' user or installation.

The two technologies will increasingly be combined; for instance, with computers decoding complicated retrieval patterns into locations in bulk microform memory that store difficult-to-digitize graphical information." (Van Dam and Michener, 1967, p. 215).

"For a number of reasons, computer-based libraries that service a wide spectrum of users, such as is found in a university, will be faced with operating on two basically different types of data—that which is digitally stored and that which is photographically stored in some microfilm form. The latter will be images of the original full text of the documents contained in the library whereas the digital data will constitute the augmented catalog of the library from which the library user gleans information about the library data and documents by conducting on-line computer searches." (Haring, 1968, p. 35).

6.2 "Recent developments have been in the area of microfilm readout devices which transfer data from magnetic tape to microfilm . . ." (Commun. ACM **10**, 387 (1967).)

"Right now the microfilm recorders—which appear to be the most promising—show signs of being successful in three major applications.

1. Direct computer output for scientific computer work where the plotting capability is required.
2. Computer applications which are in the area considered primarily data retrieval, where direct transfer to microfilm for efficient storage is a primary consideration, and hardcopy secondary.
3. When the computer is used to prepare data for graphic arts reproduction. Here is a vast new field only beginning to be opened up. (Webster, 1966, p. 33).

For example, "we (General Electric) are moving towards using computer output almost completely in microfilm form." (F. B. Campbell in "System Magazine's Third Annual Microfilm Seminar", 1965, p. 36).

6.3 "Bell & Howell's Micro-Data Div. underlines its 'yes' evaluation, that progress is being made, by pointing out that modern recording devices are placing computer information onto microfilm at speeds of up to 30,000 lines per minute. At the same point in hardware technology, modern film readers are furnishing copies of film-held information to the ultimate user in from four to ten seconds." (Kornblum, 1965, p. 36).

"National Cash Register Co. puts forth some meaty and positive thoughts relative to the survey's first query. NCR states that an increasing number and variety of EDP systems will allow for computer output to micro-image forms. Some should even permit micro-images to be used as input, with automatic conversion to digital data. This trend, continues NCR, could bring micro-image systems into EDP communications, remembering that the image systems offer higher density than any magnetic tape device can provide. Image systems can also be easily read by their human managers, whereas 'reading' of mag tape data requires relatively complex equipment. For these reasons, says the firm, manufacturers of EDP gear are gradually joining EDP and information retrieval systems, while makers of other-than-digital storage equipment are responding to the challenge with super micro-image systems." (Kornblum, 1965, p. 35).

6.4 "The Stromberg-Carlson SC–4020 microfilm plotter consists primarily of a cathode ray tube and a 35-mm camera for taking pictures of the information displayed on the face of the tube. Instructions for the SC–4020 are written on magnetic tape; the tape is then decoded by the SC–4020 and used to generate commands for opening and closing the shutter of the camera, for advancing the film, and for deflecting the beam of the cathode ray tube. Development of the film produces a 35-mm microfilm transparency which consists of lines connecting points, drawn, in effect, directly under the control of a digital computer. In this manner, the perspective points computed by an IBM 7094 digital computer are used as the input to an off-line SC–4020 microfilm plotter through an intermediate magnetic-tape storage. After photographic development, the microfilm can then be viewed directly in a stereoscope, and the final result is an illusion of depth created by a completed computerized technique." (Noll, 1966, p. 152–153).

"This system is presently being developed and is scheduled for first delivery early next year. It represents a combination of the knowledge gained in over 10 years of CRT display-microfilm recording equipment experience. The S-C 4060 is a stored program, data recording system which translates digital data into alphanumerics and graphics and records on microfilm and/or paper. The system can operate from the output of a computer or it can operate independently since it is equipped with its own computer. The S-C 4060 provides great flexibility through a variety of options. To a great degree its 'building block' modular design permits the user to match his requirements as they change." (Peterson, 1966, p. 133).

"The significant trend in output technology that began to develop in 1966 is the use of microform for computer output to achieve substantial reduction in cost, in printing time of master and dissemination copies, and in physical volume. Stromberg-Carlson's highly successful SC–4020 microfilm printer/plotter is to be updated by an entire 'micromation' line of equipment of varying capability and cost. The microfilm recorders in this series—the SC–4060, the SC–4360, the SC–4440, and the SC–4460—all convert digital codes from a computer to their alphanumeric and graphical forms on a CRT, where a camera records them. The SC–4060 printer/plotter (the replacement for the SC–4020) is used for scientific and engineering graphics and for frames for animated movies; it can plot curves, diagrams,

maps, etc. This system leases for about $8000 per month. The SC–4440 converts alphanumeric computer output into microfilm at the rate of 9000 pages per hour. Hardcopy equipment is available with these recorders. Many other manufacturers, such as California Computer Products and Benson-Lehner, have similar equipment." (Van Dam and Michener, 1967, pp. 191–192).

6.4a "The introduction by Stromberg-Carlson of Micromation—or microfilm directly produced from a computer, bypassing the paper stage . . ." (Kalagher, 1968, p. 37).

"SC 4460 recorder converts magnetic-tape material to roll film or microfiche at speeds of up to 90,000 cps. The characters are proportionally spaced and computer forms can be overlaid on the microfilm to eliminate expense of forms printing." (Berul, 1968, p. 30).

6.4b "The system combines facsimile techniques with digital processing to provide a scanning, digitizing, and playback system. Particular emphasis has been placed on the requirements of high resolution and the ability to handle large image formats. The resulting device is capable of digitizing pictorial information in 16 discrete gray levels, at a data density of 1000 elements per inch in both x and y directions. Formats up to 9 x 18 inches can be handled.

"Image data on tape, generated by computer processing, can be recorded on film by the system at the same resolution and gray-shade range as are used in scanning." (Gilman, 1966, p. 29).

6.5 "Minnesota Mining and Manufacturing's 'dry silver' Electron Beam Recorder (EBR) provides strong competition to the more traditional CRT microfilm recorders. Output is written directly on the microfilm with an electron beam at a rate of 30,000 characters per second (bypassing the traditional filming of a CRT display), thus yielding a sharper picture. Film is processed by a dry hot-air developing method (rather than the wet-stage development used with conventional microfilm), providing high-speed, real-time output. The EBR unit is expected to rent for $3000 per month, with the additional cost per microfilm page image expected to be less than two-tenths of a cent." (Van Dam and Michener, 1967, p. 192.)

"3M has a new electron beam recorder (Series F) that converts computer generated data into human readable language at speeds of 60K lines per minute on dry silver microfilm. Film is developed by heat and can be viewed instantly." (Data Proc. Mag. **9**, No. 6, 3 (1967).)

6.5a "Graphical output has been an important way of presenting results to Bell Laboratories' computer users since the fall of 1961, when a Stromberg-Carlson 4020 microfilm printer was installed at Murray Hill. It has allowed users to replace pages of tabular data with pictures that are far easier to understand. Microfilm picture generation was running recently at a rate of about 500,000 frames per year. In addition, computer movies were being generated at a rate of about 1,000,000 frames per year." (Christenson and Pinson, 1967, p. 697).

6.6 Some further details are as follows: "After an image is processed by the computer program and modified and verified by the operator at the graphic console, it is frequently necessary to produce a permanent output document of the processed image. Film is used for the output image media, as for the input media, because of its compatibility with computer speeds, flexibility of use, and high image quality. . . .

6.6a Thus it is noted that "seldom is there control of original subject matter. It varies from perfect, fresh, raised printing or litho offset to crumbling pages from archives; from clear black-and-white line copy to smudged spirit purple on yellow sulfite paper; from sharp, dense characters to burned out, illegible script, from thin, fine lines to heavy solid illustrations or even fine half-tones with four and five color separations." (Dunning, 1965, p. 14).

"CRT recording on silver film permits images to be generated by computer control at computer-data-channel speeds. The CRT used for output image recording is similar to the type used for input image scanning. As in the scanner, a CRT image is formed by vectors drawn on the CRT screen. The vector trace is visible when the beam is unblanked, in order that the beam trace can be recorded on the film. When the beam is blanked, the trace is not visible and the beam can be positioned over the image without exposing the film. An image—for example, a drawing—is divided into straight line segments. Core storage contains the X and Y coordinates of the end point of each vector. Vectors may vary in length from the very short traces required to form a smooth arc to longer traces which are used for straight line segments of the drawing." (Hargreaves et al., 1964, p. 367).

6.6b For example, Nelson found in a university library installation that the focusing lever "had been broken off, and the person who was running the equipment didn't know that it was necessary to focus it. By this time, it was apparent that the material was perfectly good . . . Here they were, ready to send $5,000 worth of stuff back because they weren't maintaining their own equipment properly." (C. E. Nelson in "System Magazine's Third Annual Microfilm Seminar", 1965, p. 39.)

Similarly, Holmes reported: ". . . Our head technician . . . found layers of dirt and a cracked lens. After these conditions were cleared up, of course, the films were no longer faded." (D. C. Holmes in "System Magazine's Third Annual Microfilm Seminar", 1965, p. 39.)

6.7 "Lockheed's experience has affirmed user acceptance to be broadly based and has brought requests to TIC management to install a microfilm catalog in R & D oriented buildings." (Kozumplik and Lange, 1967, p. 67).

"Studies at the Battelle Memorial Institute, 1961–62, identified important factors affecting satisfaction in the reading of microtext, including the especial importance of high resolution, and demonstrating that under proper conditions microreproductions can be even more readable than the originals." (Council on Library Resources, 10th Annual Report, 1966, p. 22).

"From experience with the Library of Congress, the research worker prefers to work with microfilm rather than original material." (D. C. Holmes, in "System Magazine's Third Annual Microfilm Seminar", 1965, pp. 35–36.)

6.7a "Computer-stored graphic data such as charts, graphs and grids can now be reconverted, LDX [Long Distance Xerography] scanned and transmitted to a remote printer by a device Xerox calls its LDX/Computer Adapter." (Commun. ACM **9**, 889 (1966).)

Looking forward to the not too distant future, Dunning (1965) reports: "Long range concepts of hard copy include LDX (*L*ong*D*istance*X*erography), where multiple output stations will be at variable distances from the input. Soft copy display on tubes is already here with closed-circuit TV systems. Opportunity for hard copy print-out by selective push button control at any out-put location is in the making". Present difficulties, of course, include those of high costs.

"Facsimile equipment normally requires a Schedule 2 telephotograph channel. For a small additional terminal charge, the same line can be used alternatively for voice messages." (Alden, 1964, p. 11).

". . . Xerox Corporation's work in facsimile . . . LDX, which stands for 'long distance xerography' . . . The equipment, at the output end, is much like our Xerox 914 or 813 copier. The input, however, may be some distance away, up to thousands of miles away, if necessary . . . We propose, in order to produce high quality, that we scan the original document at approximately 200 lines per inch. . . .

"The LDX system is presently designed for full-size originals at the transmitting end, but it is a straightforward design job to provide means to accept the input in the form of microfilm." (Mayo, 1964, pp. 77–78).

"The STARE hard-copy facility accommodates up to eight rapid hard-copy output stations. The system consists of multiple remote Xerox LDX (Long Distance Xerography) Printers interfaced to a central buffer memory and control unit that is located near the GE–645. The LDX printers form an image by a raster scan technique, so the data from the central buffer unit to the printers are essentially a video signal for controlling the intensity along each scan line. These data to the LDX Printer are transmitted from the central buffer at about a 250,000-baud date over coaxial cable links. There are eight separate buffer areas on the magnetic drum which function independently. Therefore, transmission to up to eight printers can take place simultaneously." (Christenson and Pinson, 1967, pp. 699–700).

6.7b "Another scanning converter built by United Aircraft Corporation for the USAF feeds computer output directly to a local facsimile recorder or out over a network without any intermediate hard copy." (Alden, 1964, p. 13).

6.7c "Remote copying and the computer have been successfully merged at Bell Telephone Laboratories. The link-up . . . joins computer-generated data display with Xerox's Graphic Terminal Hardcopy Printer System . . . The graphic terminal has its own core memory consisting of 125,000 bits and a drum memory of 11 million bits. The latter can store 8 individual images. By using memory units for temporary storage of the signals as a buffer, the terminal is able to regulate the flow of data in scan line form to the printers at a speed of one page every seven seconds." ("Just Merged . . .", 1967, pp. 50–51).

6.8 "General Precision, Inc., Pleasantville, N.Y., has been working for a number of years on equipment designed to transmit microfilm images by closed circuit television . . . The latest version shown at the 1965 Western Electronic Show included the GPL TV Printer which allows the user to take a hard copy of whatever he is viewing on the screen. Prints 8.5″ x 11″ are delivered in about half a minute by rapid processing of conventional silver halide paper." (Veaner, 1966, p. 208).

6.9 "On October 2, 1957, a proposal was submitted to the Council on Library Resources by a manufacturer of closed-circuit television equipment for design and construction of a prototype, remotely controlled, catalog card viewing system. The proposed 'Telereference' system would permit a researcher to view catalog cards in a central catalog from a remote location by the use of closed-circuit television and a remotely controlled card manipulator." (Bacon et al., 1958, p. 1).

6.10 "All the libraries in the Lake County Library system share in a growing book collection . . . A union catalog in book form, in single or multiple copies as required, is furnished to each participating library; the closed circuit teletype communication provides the necessary means of sharing the common collection as reflected in the union catalog." (Burns, 1964, p. 14).

6.11 "One laboratory will have a closed-circuit TV link with the computer so that a graphical presentation (plotted curves as well as alpha and numeric information) of computer output will be available at the remote terminal." (Neilsen, 1965, p. 635).

6.11a "The idea behind this [video-storage display] device is to take advantage of the very low cost of commercial TV for the display and to utilize reasonably inexpensive magnetic drum or disk storage to record the video data for the display memory. Rapid strides in high-density magnetic recording have made this console a reality. Brookhaven Laboratory has an operational 10 station

video-station of their own design [Brad]." (Stotz, 1968, p. 14).

6.11b "A new records retrieval system called Remstar is now available from Remington Office Systems. With Remstar, closed circuit television is combined with automated records retrieval units to not only locate records, but to transmit them as well." (Systems **7**, 6 (1966).)

6.12 "All told, twenty or more non-impact devices are being, or have been, marketed. They vary widely in their capability and cost. Those which are extremely fast tend to have poor print quality. Those which offer sufficient quality are limited to one-ply, or may require additional processing to obtain even the single copy." (Webster, 1965, p. 43).

6.13 "The typical computer-printer or tabulating machine produces monospaced upper case characters, that is, evenly spaced capital letters. The result is a monotonous looking product with no typographic variation between captions and body. There is little reader appeal and the eye must work overtime to find what it wants from the printed page." (Lannon, 1967, p. 81).

"As long as Mr. Watson would only give us a character font in capital letters there could not be any great fervor to load [machines with bibliographic information records]. If I may say so, the whole picture of automation in libraries from the thirties right down to the present date has been controlled by that uppercase limitation." (Clapp, 1964, pp. 54–55).

6.14 "[The upper-case limitation] reduces readability so much that the page layout must be extremely open if the material is to be usable at all." (Kraft, 1963, p. 275).

"A major disadvantage of computer print-out is its poor legibility and its low information density." (Corrado, 1965, p. 271).

"It has been reported that 20 percent of the total volume printed by the Government Office is data assembled by computer. In general, such material has been either printed out then keyboarded again for typesetting or the printout has been simply photographed and reproduced. In the latter case, the printed material is less legible than if it were typeset, and 40 percent more bulky." (Webster, 1966, p. 33).

6.15 "The IBM 1403 chain printer involves use of a continuously moving chain consisting of 240 character positions usually divided into 5 sets of 48 characters each, so as to minimize access time to the appropriate characters to be selected. However, by redividing, a character set of 120 can be accommodated, although at significant loss (up to 50 percent-60 percent) of printer speed. This technique is used, for example to provide upper and lower case for the KWIC index, *Chemical Biological Activities* . . . In addition, the cover of the Proceedings of the Literary Data Processing Conference [Bessinger et al., 1964] illustrates an experimental concordance of the *Gothic Bible* which 'employs the upper- and lower-case print chain, and . . . a new technique of printing boldface by overstriking the headword in each citation'." (Stevens and Little, 1967, pp. 73, 75).

6.16 "The Potter Chain Printer, Model PS–6020, operates at up to 600 lines-per-minute and features interchangeable type fonts and up to 192 different characters." (Commun. ACM **9**, 651 (1966).)

"The Model PS–6020 Off-line Printer utilizes the Potter Model SC–1060 tap unit, and the Model PS–6030 utilizes the Model SC–1080 tape unit. Both models use Potter's HSP–3502 Chain Printer. The chain printing mechanism permits precise vertical registration, which is difficult to achieve with drum printers . . .

"The HSP–3502 Chain Printer prints one to six copies on forms 2.5 to 18.5 inches wide. Standard fan-fold or roll forms, heat transfer or pressure-sensitive papers, card stock, and multilith masters can be printed in lengths of up to 44 inches per form . . .

"Ten numerals, 26 upper-case and 26 lower-case letters, and 30 symbols are available for inclusion in the printing character set. Any special character or symbol can be provided optionally. Character sets of any size up to 192 characters, made up of any combination of numerals, letters, and special symbols, can be provided." (Melick, 1967, p. 46).

6.17 "Mechanical output printers have increased in speed to the point where they are now commonly producing 600 to 1,000 lines per minute (2,000 cps) depending upon many factors, including the size of the repertoire or character set. . . .

"A one-thousand-line per minute printer with 120 print positions can create text at the rate of 2,000 characters per second. The character set used in this extremely rapid process is, however, very small and it is manipulated without any of the control devices (justification, leading, etc.) used by typesetting machines." (Sparks et al., 1964, p. 177).

6.17 "To achieve Thermal Printing, two novel components are utilized. The first, a print head, is an array of resistors selectively heated electrically to generate a thermal image. The second is a thermal sensitive paper which is held in contact with the print head to provide a printed record of the thermal image. . . .

"Five wafers are mounted together to form a print head (Figure 1c). Each print head contains ten 5 x 5 matrices; each matrix is capable of printing one character. Eight print heads are mounted side by side in the printer to achieve the 80 character line. . . .

"The Thermal Printer can print data received at any mixed rate of input—including input from a keyboard. The rate of input has been tried and tested at rates as high as 240 characters/sec which is certainly not the upper limit. Since we also get an electronic, nonimpact printer which appears to be very reliable and can produce multiple copies on plain paper, thermal printing may have potential application in many systems—both communications

systems and automatic data processing systems." (Joyce and Homa, 1967, pp. 261–262, 267).

6.18 Further, the system modifications will provide for multiple use of a battery of printers. "In a system of 32 printer terminals a translator clock derives a sequence control which is connected to a 5-bit printer scanning buss. Each printer is set to recognize its own scan number and will respond to the column print pulses on the print buss only if it has been addressed and only when it is scanned." (De Paris, 1965, p. 49).

6.18a "USAECOM has also sponsored a development of Miniaturized Techniques for Printing (MINIPRINT) with NCR. This is an exploratory development printer which prints at 15 characters/second, can be operated from a keyboard, and was developed for potential use as a self-contained, battery operated, tactical teleprinter. The package size of the present model (cigar-box size) may also contain all the required electronics. The printing is immediately visible on new thermal sensitive master paper. The master and first copy are made simultaneously in this printer and at least ten legible copies can be obtained using the master copy and plain paper in an off-line pressure device." (Joyce and Homa, 1967, p. 267).

6.18b "New teleprinter devices have recently come on the market. Included are a high speed electrostatic printer and an ink jet, which squirts charged ink particles onto the page, deflecting the ink jet with electrostatic plates. The added printing speed makes these devices attractive as printers; but both units shield the printed line from the view of the user until the line is complete which limits their utility in an on-line terminal. Furthermore, their complexity means a higher price tag although they remain alphanumeric devices." (Stotz, 1968, p. 13).

6.18c Webster also reports that "the Radiation 'Super-Speed' printer has a single line of styli extending across the continuously moving paper. These also are pulsed several times to form characters from top to bottom, and by this means a speed of over 31,000 lines per minute is achieved." (Webster, 1966, p. 32).

6.18d "Electronic methods for changing character size may be employed, for example, by zooming. The images produced on the CRT face are focused onto a microfilm strip which then, after development and printing, becomes the hard copy output record." (Potter and Axelrod, 1968, p. 2).

6.19 For example, as described by Barnett, Kelly, and Bailey: "In photocomposition . . . successive characters along a line are displayed with collinear base lines, regardless of their magnification (i.e.) point size. . . . The same character is displayed in different point sizes, in photocomposition, by the use of different lenses. . . . Special characters can appear anywhere in a text, and can be magnified and spaced in the same ways as ordinary alphabetic characters." (Barnett et al., 1962, pp. 60–63).

6.20 "However, since all photocomposers existing or under development appear to use photographic recording, we can start at the light-sensitive emulsion, and explore the various methods used to form and position the optical images. High-speed photocomposers generally fall into six principal categories:

a. Those which have a stationary master glass grid from which the symbols are selected, sized and positioned onto the photographic emulsion by purely optical-mechanical means. An example of this is the Mergenthaler Linofilm System.

b. Those which have the symbols on a spinning master glass grid and a single stroboscopic flash tube that can be flashed at the proper instant to select any desired character, with size control, imaging and positioning by optical-mechanical means. Examples of this are the Photon 200, 500, and 700 series machines and the Harris-Intertype spinning disc photocomposer.

c. Those which have the symbols on a stationary master glass grid, with a separate flash tube for each symbol, a reciprocating lens which positions all symbols across a complete line through an optical tunnel, with the various flash tubes being fired as each symbol is imaged in each of its desired positions in the line, permitting a complete line to be composed in one pass of the lens. The only machine of this type is the Photon 900 (Zip or GRACE) machine, the first of which was delivered to the National Library of Medicine in 1964.

d. Those which have the symbols on a stationary master glass grid, steadily illuminated and optically projected onto a light-sensitive cathode of an image-dissecting tube, which simultaneously produces scanned video electron beams from all symbols, one of which is allowed to pass through an electrostatic wire grid selection matrix to produce a video brightening signal for a high-resolution cathode-ray display tube, with positioning and size on the display tube being controlled electronically The only such machine of this type is the Mergenthaler-CBS Linotron system being developed for delivery to the Government Printing Office and the Air Force in 1967, employing the CBS "Reconotron" image dissector-scanner, and the CBS "Microspot" high-resolution cathode-ray display tube.

e. A special cathode-ray tube employing a beam-shaping metal plate perforated with the symbol shapes, with means to cause the electron beam to impinge on any symbol area, emerging as a shaped electron beam, which can be deflected to display the symbol at any position on the face of the cathode-ray tube. An example is the Charactron tube, employed in photocomposers built by the Stromberg Carlson Division of the General Dynamics Corp.,

such as the S-C 4020. The repertoire of symbols is usually severely limited to less than 100.

f. Methods employing a conventional or high-resolution cathode-ray tube to display the symbols as they are generated by some means which will produce suitable beam deflections and video brightening to form the symbols." (Stevens and Little, 1967, p. 22).

6.20a "The year has seen remarkable progress in the field of phototypesetting. Photon, Inc. added to its 713 line. The model 713–5 operates at 30 newspaper lines per minute. Fairchild Graphic Equipment entered the field with two machines, the Photo Text Setter 2000 and the Photo Text Setter 8000. American Type Founders also announced an addition to its line of phototypesetters, to be known as the ATF Photocomp 20 . . .

"Alphanumeric, Inc., has a new very high-speed phototypesetting machine that is being used in its service center at Lake Success, Long Island. And Harris-Intertype is producing a CRT type of fast phototypesetting machine, the first of which was scheduled to be installed at Baird-Ward Co., Nashville, Tenn., near the end of 1967.

"K. S. Paul & Associates, London, England, also has a CRT type of phototypesetting machine. It is not quite as fast in its operation as the ones mentioned above, but is less expensive. Mergenthaler Linotype Company has announced that it will market this machine in the United States under the name of Linotron 505." (Hartsuch, 1968, p. 61).

6.21 "The A. B. Dick Videograph tube transfers characters by means of a set of fine wires embedded in its face." (Webster, 1965, p. 43).

"A. B. Dick Co.'s Model 904 Videograph Page Printer translates a digital coded input into a printed output at the rate of 7200, 130-character lines per minute." (Data Proc. Mag. **7**, No. 2, 51 (1965).)

"The Videograph electrostatic printing process uses a special cathode ray tube for creating alphanumeric characters on dielectrically coated paper at rates in the order of 10,000 characters per second. In electronic data processing systems, the source data are usually provided from computer-prepared magnetic file tapes. The binary-coded signals from the tape are decoded in the Videograph system by means of an electronic character generator into the video signals necessary to modulate the printing tube and create the character shapes. The principal application of Videograph printers has been to produce address labels of the type used on magazines, newspapers, and direct mail." (Gerlach, 1968, p. 17).

6.22 "Perhaps the best quality is produced by the Stromberg-Carlson 'Charactron' shaped-beam tube which uses a tiny 64-character mask within the tube itself. The images displayed on the tube are captured by microfilm in the S-C 4020, or printed electrostatically in the low-cost S-C 3070." (Webster, 1965, p. 43).

"The SC 4020, on-line to the computer, uses a charactron tube which can produce the letters of a line of information onto the face of a cathode-ray tube. It does this by plotting on the tube the coordinate points which make up the shape of an individual letter. The result is optically projected, a line at a time, to a spool of moving, unexposed film." (Becker, 1967, pp. 3–4).

". . . [The SC–4020] composes characters and symbols at a rate of 17,400 per second. The characters are formed by directing a beam at the desired character; then horizontal and vertical deflection circuits deflect the selected character to the appropriate spot on the CRT display. This technique has also been successfully combined with a dry process Xerographic printer which has achieved a composing rate of 1 million characters per minute." (Sparks et al., 1964, p. 180).

"Our investigations at RSIC [Redstone Scientific Information Center] have indicated that today the CHARACTRON tube can give the best quality within the state-of-the-art." (Burger, 1964, p. 12).

6.23 "The Linotron consists of three main units: Control, Character Generation, and Display. Magnetic tape is the input for this machine. This tape contains all data characters and control codes required to operate the photocomposer. Four grids, each containing 255 characters, can be loaded into the Linotron. The character generator can position the required grid in one-half second and select any character on the grid at electronic speeds. (There are no shutters or other mechanical devices involved in character generation.) The output of the character generator is an electric signal which serves as an input to the display section. The beam of the display tube is positioned to the required X- and Y-coordinates; then the signal from the character generator causes the character to be scanned out on the surface of the display tube. This character is projected through a lens onto the film. The beam is then positioned for the next character and this process is repeated until the page is complete. There is no mechanical motion of any kind while the page is being composed. The film is advanced only after the page has been completed." (Rollert, 1968, p. 7).

6.24 "RCA recently unveiled a new computer-controlled photocomposing system called VIDEO* COMP. With this system, it is possible to store the analog equivalent of several type fonts and styles. This enables the user, in the final printing stage, to select a variety of intermixed type fonts and styles with virtually no restrictions. It results in page copy which resembles letter press quality in terms of page makeup precision and aesthetic appearance." (Becker, 1967, p. 3).

"Videocomp is the generic name which RCA has given to electronic composition systems and equipments which employ high-speed cathode ray tube (or equivalent) photocomposing techniques. These systems and equipments are capable of greater speed and flexibility than first generation optical-mechanical photocomposers. The 70/822 Videocomp is the output system which performs the actual photocomposition in response to magnetic tape data and control input. The 70/9300 Video-

comp Electronic Composition System is an integrated system which includes the 70/822 Videocomp and executes the complete composition process from manuscript to final photocomposed page." (Coleman et al., 1968, p. 30).

"A new all-electronic typesetter that can set the complete text for a magazine page in less than four seconds or write information for microfilm storage at computer speeds has been announced by RCA, New York, N.Y. The Videocomp 70/830 generates characters at a rate of up to 6,000 per second—a thousand times faster than manual typesetting machines. Additionally, the Videocomp provides full page composition through its 70 pica (12 inch) line length and its ability to write in sizes from 4 to 96 point type (approximately $1\frac{1}{3}$ inches high) with proportional reduction for 35mm microimage output.

"Videocomp can be used to set type in almost every format conceivable—from a full page tabloid newspaper composition to directories or parts manuals. Equally important, the new equipment makes possible quality typeset printout of computer information at speeds well in excess of the 1,100 lines per minute typical of high-speed printers now used for computer readout. This could result in easier handling and reading of the business and scientific data now being processed by computers.

"In operation, original copy and composition instructions are fed to a computer which produces an output magnetic tape or sends signals directly to the 70/830. In response to taped or direct signals, the machine generates characters on a cathode ray tube. As the characters appear on the tube they expose standard or 35 microimage film, stabilization paper for quick proofing, or short run offset plates.

"Videocomp stores typefonts in electronic memory where they can be used instantly. This internal storage reduces load on computer memory and permits use of the Videocomp off-line with any computer.

"Because the entire operation is electronic, every letter can be altered electronically to form roman, oblique, extended, condensed and superior and inferior versions of the basic face. Every face, in every variation, can be mixed at will—on the same line, in the same word—with every other face. In addition, Videocomp can store and write any special form including scientific, mathematical and engineering symbols, foreign alphabets, ideographs or trademarks—literally, almost any visual image." (Computers and Automation **17**, No. 4, 63 (Apr. 1968).)

6.25 "The Digiset developed by Dr. Rudolf Hell of Kiel utilizes an 8-bit character selection code and it sets justified and hyphenated lines of 11, 18, or 28 picas at rates of up to 400 characters per second. . . . In a telephone directory application, the character set consisted of 180 alphanumeric and other symbols. Character patterns are stored in a core memory of 180,000–190,000 bit capacity. A character set may be replaced with an alternate set of 180 characters by transfer from auxiliary store in approximately one-half second." (Stevens and Little, 1967, pp. 33–34).

6.25a "Scores of printing jobs can be typeset up to six times faster than before with a computer-controlled photocomposition unit announced by IBM Corporation, White Plains, N.Y. The new device called the IBM 2680 CRT printer, is the first of its kind to tap the full power of a computer. It can be used for a variety of typesetting jobs, including books, newspapers, catalogs and directories. Linked directly to an IBM System/360, it can set graphic-quality type at speeds ranging as high as 6,000 characters a second.

"The 2680 CRT printer is operated completely under the control of System/360. Draft copy is usually fed into the computer on paper tape or magnetic tape, but it can be entered through any System/360 input device. A user can choose from a large variety of type styles and sizes—all stored magnetically on the disc files seen in the foreground of the picture.

"The computer formats and justifies the copy, automatically hyphenating words that break between lines. It then commands the 2680 to write the finished text electronically on a television-like cathode-ray tube (CRT)." (Computers and Automation **17**, 58 (Jan. 1968).)

6.25b "Consideration is given to the possibility of providing a computer and a cathode ray printer with an unlimited repertory of characters. Digitalizations are presented for mathematic, cartographic, and calligraphic characters. The repertory is available to any computer through FORTRAN IV programming. The latest cathode ray printers are almost adequate for the preparation of mathematical reports." (Hershey, 1967, ii, abstract).

Some of the problems of character and symbol generation are discussed in another report in this series involving overall system design requirements, especially, character set considerations.

6.26 Automatic hyphenation methods required for line justification variously involve the use of dictionary or table lookups, suffix and prefix splitting, logic rules, and combinations of these techniques. Automatic hyphenation techniques for languages other than English include those for Dutch, French, German, and Italian as reported in the "Computer Typesetting Conference Proceedings," The Institute of Printing (1965).

6.26a "The dot or raster mode of the system is used to generate half-tone pictures. The machine can generate any desired dot density and practically any resolution up to a maximum of 660 dots per inch in either field direction." (Potter and Axelrod, 1968, p. 5).

6.26b "An added feature common to the modern CRT is the ported window at the rear of the tube. The port is designed so that static overlays such as maps can be projected from a slide or film clip onto the face of the CRT. The overlay relieves the display

of the need to continuously regenerate static data." (Mahan, 1968, p. 19).

"Static information can be superimposed on the beam written data by projecting pictures (slides) through an optical port in the CRT. Typical systems can select from among 25–150 slides." (Machover, 1967, p. 157).

"So that an optically projected image can be combined with the electronically generated image, CRT's in terminals supplied by Bunker-Ramo and Stromberg-Carlson have a window through which a picture can be projected onto the screen." (Machover, 1967, p. 150).

6.26c "Techniques with the greatest potential are all based on photocomposition. Photon was the first to introduce a spinning-disk type of photocomposer. The Photon 900 or 'Zip' is the machine employed in the GRACE system at the National Library of Medicine to produce Index Medicus, described by Austin. It is a text-only machine capable of operating at speeds on the order of 250 characters per second from magnetic tape input. The improved Photon 901 overcomes the problems of variable character density and variable base lineup of characters, and also has an attachment for inserting graphics from projected slides." (Amer. Institute of Physics Staff, 1967, pp. 355–356).

6.27 Relatively early examples are discussed in the 1961 report of Buck et al. Then we note: (1) "The tonal scale of the illustration is simulated in the printing process by making the dot pattern structure on the printing press plate a function of the tonal gradations of the original illustration. Thus the dark areas of the original illustration are represented by a dot pattern in which the dots are relatively large and with little white space between the individual large dot areas . . .

(2) "The output graphic must be a dot pattern structure in which the distribution of the dots over the image area represents a faithful reproduction of the continuous tone input image. It should be noted that since the dot pattern structure does not appear in the input graphic, it must be created within the LGCP system." (Mergenthaler, 1963, p. 13).

6.28 [In a Lexical-Graphical Composer-Printer (LGCP) system at Wright-Patterson AFB], "The Video Graphics Copier converts illustrations to video tape. The Format Processor accepts full-text coded mag tape, effects composition, and produces an instruction tape. The photocomposer accepts the instruction and video tapes as input, is driven by the instruction tape to select and position data characters onto the output and to insert the graphics from the video tape when necessary, and creates fully-composed pages in the form of film positives." (Kehler, 1968, p. 119).

6.28a "The need for hard copy which the user can take to his office for contemplation still exists, however. We currently use Polaroid photographs, but the need for a more convenient and larger copy . . . was often expressed." (Evans and Katzenelson, 1967, p. 1143).

"For many situations the operator may desire hard-copy text of the image on the display. Two means are currently employed. A Polaroid photograph provides a quick copy adequate for many purposes. For complex drawings where more resolution is required, or where it is desirable to be able to write on the copy, the . . . MODEL T [a] device can provide signals for either a digital or analog mechanical plotter." (Miller and Wine, 1968, p. 475).

"The hard copy should be of high enough quality to reproduce legibly the information on the display, (although it probably need not be of record-keeping quality). Another important consideration is that the copying process should not materially delay the user from going on with his work while printing takes place." (Stotz, 1968, p. 16).

"Hard-copy outputs can be provided, where needed, by a variety of devices, ranging in speed from typewriter rates of 10–15 cps up to 60,000 cps. The high-speed end of the range tends to be impractical because broad-band communication lines are needed and they are very expensive." (Berul, 1968, p. 29).

6.29 For example, "The information system's designer is faced with a dilemma. If he provides for unlimited hard copy service, a major portion of his budget is absorbed in fulfilling hard copy requests. If he insists that obtaining hard copy is the user's responsibility, he and the user may unwittingly be with-holding information which may be extremely valuable. The 'missed' item in some instances could exceed in value the total cost of operating the information system.

"A third aspect of the hard copy dilemma is attempting to satisfy a need which may not be related to either use or value. This need will be called the 'Possession is Security Syndrome' or frequently referred to as the 'pack rat instinct'. It is a very important aspect often encountered in investigations of users' needs and satisfactions—yet it is little understood in the documentation area." (Resnick, 1964, p. 317).

"The real answer to the hard-copy problem requires convincing users that they will never lose easy access to information they have once uncovered. This is far from a trivial problem in documentation and we seem no further along towards solving it than we were a decade ago." (Ohlman, 1963, p. 194).

6.30 "Developments include electrostatic printing, magnetic printing, smoke printing, thermal recording, thermoplastic recording, and photographic recording. Many of these techniques can be applied to the making of replica copies of existing documents as well as to generating the initial copy of a document from an electronic or digital store." (Sparks et al., 1964, p. 181).

6.31 "Photographic film of the text will then be provided in a format suitable for an automatic character reader . . .

"The planned separation method is semi-automatic in that decisions to separate text from

graphics are to be made by a human operator." (Bus. Automation **12**, No. 8, 66, Aug. 1965).

6.31a "The area of microfilm-to-hard-copy conversion is not yet very advanced. There are a number of reader-printers, such as the Itek 1824 or the 3M Filmac 200, which under operator control can make copies from any type of microfilm. The problem, however, is that the process is too slow and the cost of the copies too high for production volumes." (Berul, 1968, p. 30).

6.31b "The emphasis was on making it easy to use the system to obtain information. This included such things as producing printed output which would not look like an accounting ledger, but would be similar to the majority of printed documents people are used to reading and which would provide visual cues for ease of scanning and interpretation." (Ebersole, 1965, p. 172).

6.31c Further, ". . . IDEA provides for displays of specified variables. At present these include frequency distributions and contingency tables. We also intend to provide other plots, scatter diagrams, etc., with such aids as discriminant functions, regression analysis, iso-probability, and iso-distant curves derived under various assumptions." (Press and Rogers, 1967, p. 39).

6.32 "The properties and techniques by which a high-speed printer can be made to emboss regular printing paper with braille symbols is described in Sterling et al. . . ." [Sterling, T. D., M. Lichstein, F. Scarpino, D. Stuebing and W. Stuebing, "Professional Computer Work for the Blind", Commun. ACM **7**, 228 (1964)]. (Landwehr et al., 1965, p. 302).

Then, "at MIT one aspect of work to aid the blind includes coupling of a high-speed electric Braille typewriter and a small computer to achieve an inexpensive conversion of machinable documents into Braille code." (E. Glaser, report of panel discussion on Computers and Aid to the Handicapped, Commun. ACM **8**, 638 (1965).) Kehl (1965) also mentions the M.I.T. high-speed Braille printer.

It is of particular interest to note in this connection that "initial experience with several trainees indicated that the blind programmer equipped with routines which print input, output and/or memory contents in braille is no more dependent on external help than is his sighted colleague." (Landwehr et al., 1965, p. 300).

Nelson (1965) has also explored some of the possibilities for on-line Braille display.

6.33 An example of current research in this area is provided in Quarterly Progress Report No. 80, The Research Laboratory for Electronics, M.I.T. More specifically: "By a judicious choice of elements for the lexicon and the use of a set of very simple algorithms it is possible to decompose a word in an orderly fashion into the stored elements from which the phonemic translation can be found. A lexicon containing approximately 32,000 elements is sufficient for the decomposition of all entries in the Seventh Edition of Webster's 'New Collegiate Dictionary'. Additional markings in the lexicon provide the basis for the resolution of syntactical ambiguities which cannot be handled by the phonic approach." (Quarterly Progress Report No. 80, Research Laboratory for Electronics, MIT, 225 (1966).)

"An efficient scheme has been developed for the automatic translation of English text from letters to phonemes. This process of translation is an indispensable part of a reading machine that produces synthetic-speech output." (Quarterly Progress Report No. 80, Research Laboratory for Electronics, MIT, 225 (1966).)

"The problem of automatic translation from letter spelling to phonetic spelling in English text has been studied. A procedure has been developed, based upon a 'dictionary' of approximately 30,000 root words and a set of combination and generation laws, such that the correct pronunciation (phonetic spelling) of 250,000 English words can be automated." (Quarterly Progress Report Research Laboratory for Electronics, No. 80, MIT, 218 (1966) further ref. to F. Lee Ph.D. Thesis, EE. Oct. 1965).

A project at the Institut für Phonetik und Kommunikationsfordung, University of Bonn, has both FAP and COMIT language programs written to explore this possibility.

6.34 Project of A. Risberg, Royal Institute of Technology, Stockholm, Sweden. (Stevens, 1968, pp. 21–22).

"*A conference on compressed speech*, sponsored by the Division for the Blind . . . The method may be used by students as a review technique and by blind persons to increase their reading rate appreciably when using recorded books." (L C Inf. Bull. **24**, 674 (1965).)

See also note 5.60, p. 98.

7. System Use and Evaluation

7.1 "The [test or sample] problems were invariably simple because generally any typical problem would require the amassing of considerable data and its manual manipulation to determine check-points for system rating. The expense involved was considerable and generally was not approved by the pertinent management groups." (Davis, 1965, p. 82).

"The quantitative data, the analyses, and the conclusions about man-computer systems that one seeks in a controlled experiment will emerge only if the data-reduction effort is painstakingly planned and executed." (Morey and Yntema, 1965, p. 356).

7.2 "One of the most difficult problems in evaluating information retrieval systems is to identify meaningful evaluation criteria. Most of the im-

portant criteria can be directly related to cost, reliability and time." (King and Terragno, 1964, p. 393).

". . . No quick and simple evaluation procedure which is both conceptually coherent and empirically convincing is possible. There is not, in fact, widespread agreement or conviction as to what would qualify as a criterion for evaluating an information system." (Ossorio, 1965, p. 52).

7.3 "The value of an information system is, therefore, connected with user performance and capability which may only be assessed in a qualitative manner." (Blunt, 1965, p. 9).

"The setting up of criteria of evaluation, on the other hand [in contrast to measures of effectiveness] demands user participation and provides an indication of whether the user understands the reason for the system, the role of the system and his responsibilities as a prospective system user." (Davis, 1965, p. 82).

Appendix B. Bibliography*

Abramowich, J., Storage Allocation in a Certain Iterative Process, Commun. ACM **10**, No. 368–370 (June 1967).

Adams, C. W., Responsive Time-Shared Computing in Business—Its Significance and Implications, AFIPS Proc. Fall Joint Computer Conf., Vol. 27, Pt. 1, Las Vegas, Nev., Nov. 30–Dec. 1, 1965, pp. 483–488 (Spartan Books, Washington, D.C., 1965).

Adams, S., Information—A National Resource, Am. Doc. **7**, No. 2, 71–75 (April 1956).

Alden, W. L., Cutting Communication Costs with Facsimile, Data Proc. Mag. **6**, 11–14 (Sept. 1964).

Allen, J., Machine-to-Man Communication by Speech Part III: Synthesis of Prosodic Features of Speech by Rule, AFIPS Proc. Spring Joint Computer Conf., Vo.l 32, Atlantic City, N.J., Apr. 30–May 2, 1968, pp. 339–344 (Thompson Book Co., Washington, D.C., 1968).

Amdahl, G. M., Multi-Computers Applied to On-Line Systems, in On-Line Computing Systems, Proc. Symp. sponsored by the Univ. of California, Los Angeles, and Informatics, Inc., Los Angeles, Calif., Feb. 2–4, 1965, Ed. E. Burgess, pp. 38–42 (American Data Processing, Inc., Detroit, Mich., 1965).

American Institute of Physics Staff, Techniques for Publication and Distribution of Information, in Annual Review of Information Science and Technology, Vol. 2, Ed. C. A. Cuadra, pp. 339–384 (John Wiley & Sons, Inc., New York, 1967).

Anderson, H. E., Automated Plotting of Flow-Charts on a Small Computer, Commun. ACM **8**, 38–39 (Jan. 1965).

Aoki, M., G. Estrin and R. Mendell, A Probabilistic Analysis of Computing Load Assignment in a Multiprocessor Computer System, AFIPS Proc. Fall Joint Computer Conf., Vol. 24, Las Vegas, Nev., Nov. 1963, pp. 147–160 (Spartan Books, Baltimore, Md., 1963).

Appel, A., Some Techniques for Shading Machine Renderings of Solids, AFIPS Proc. Spring Joint Computer Conf., Vol. 32, Atlantic City, N.J., Apr. 30–May 2, 1968, pp. 37–45 (Thompson Book Co., Washington, D.C., 1968).

Appel, A., The Notion of Quantitative Invisibility and the Machine Rendering of Solids, AFIPS Proc. Spring Joint Computer Conf., Vol. 32, Atlantic City, N.J., Apr. 30–May 2, 1968, pp. 387–393 (Thompson Book Co., Washington, D.C., 1968).

Applebaum, E. L., Implications of the *National Register of Microfilm Masters*, as Part of a National Preservation Program, Lib. Res. & Tech. Serv. **9**, 489–494 (1965).

Arnovick, G. N., A Computer-Processed Information-Recording and Association System, in Statistical Association Methods For Mechanized Documentation, Symp. Proc., Washington, D.C., Mar. 17–19, 1964, NBS Misc. Pub. 269, Ed. M. E. Stevens et al., pp. 181–184 (U.S. Govt. Printing Office, Washington, D.C., Dec. 15, 1965).

Aron, J. D., Real-Time Systems in Perspective, IBM Sys. J. **6**, No. 1, 49–67 (1967).

Austin, C. J., Dissemination of Information and Problems of Graphic Presentation, Proc. 1965 Congress F.I.D. 31st Meeting Congress, Vol. II, Washington, D.C., Oct. 7–16, 1965, pp. 241–245 (Spartan Books, Washington, D.C., 1966).

Automatic Typesetting, First International Technical Information Congress, La Compaigne Francaise d'Editions, Paris, 1965, 374 p.

Bacon, F. R., N. C. Churchill, C. J. Lucas, D. K. Maxfield and C. J. Orwant, Application of a Telereference System to Divisional Library Card Catalogs: A Feasibility Analysis, Final Rept., 91 p. (Engineering Research Inst., Michigan Univ., Ann Arbor, May 1958).

Bagg, T. C. and M. E. Stevens, Information Systems Retrieving Replica Copies: A State-of-the-Art Report, NBS Tech. Note 157, 172 p. (U.S. Govt. Printing Office, Washington, D.C., Dec. 31, 1961).

Baker, C. E. and A. D. Rugari, A Large-Screen Real-Time Display Technique, Inf. Display **3**, 37–46 (Mar./Apr. 1966).

Baker, F. T. and W. E. Triest, Advanced Computer Organization, Rept. No. RADAC–TR–66–148, 1 v. (Rome Air Development Center, Griffiss Air Force Base, N.Y., May 1966).

Barnett, M. P., K. L. Kelley and M. J. Bailey, Computer Generation of Photocomposing Control Tapes, Part 1, Preparation of Flexowriter Source Material, Am. Doc. **13**, No. 1, 58–65 (Jan. 1962).

Barnett, M. P., D. J. Moss, D. A. Luce and K. L. Kelley, Computer Controlled Printing, AFIPS Proc. Spring Joint Computer Conf., Vol. 23, Detroit, Mich., May 1963, pp. 263–288 (Spartan Books, Baltimore, Md., 1963).

Barnett, M. T., Computer Typesetting: Experiments and Prospects, 245 p. (M.I.T. Press, Cambridge, Mass., 1966).

Barton, R. S., A Critical Review of the State of the Programming Art, AFIPS Proc. Spring Joint Computer Conf., Vol. 23, Detroit, Mich., May 1963, pp. 169–177 (Spartan Books, Baltimore, Md., 1963).

Baruch, J. J., A Medical Information System: Some General Observations, in Information System Science and Technology, papers prepared for the Third Cong., scheduled for Nov. 21–22, 1966, Ed. D. E. Walker, pp. 145–150 (Thompson Book Co., Washington, D.C., 1967).

Bauer, W. F., On-Line Systems—Their Characteristics and Motivations, in On-Line Computing Systems, Proc. Symp. sponsored by the Univ. of California, Los Angeles, and Informatics, Inc., Los Angeles, Calif., Feb. 2–4, 1965, Ed. E. Burgess, pp. 14–24 (American Data Processing, Inc., Detroit, Mich., 1965).

Becker, C. H., UNICON Computer Mass Memory System, AFIPS Proc. Fall Joint Computer Conf., Vol. 29, San Francisco, Calif., Nov. 7–10, 1966, pp. 711–716 (Spartan Books, Washington, D.C., 1966).

Becker, J., Technology in Information Presentation, transcript of lecture delivered to the Institute of Management Science, Washington, D.C., Chapter, Nov. 1, 1967, 12 p.

Becker, R. and F. Poza, Natural Speech from a Computer, Proc. 23rd National Conf., ACM, Las Vegas, Nev., Aug. 27–29, 1968, pp. 795–800 (Brandon/Systems Press, Inc., Princeton, N.J., 1968).

Bell, G. and M. W. Pirtle, Time-Sharing Bibliography, Proc. IEEE **54**, 1764–1765 (Dec. 1966).

Benner, F. H., On Designing Generalized File Records for Management Information Systems, AFIPS Proc. Fall Joint Computer Conf., Vol. 31, Anaheim, Calif., Nov. 14–16, 1967, pp. 291–303 (Thompson Books, Washington, D.C., 1967).

Bennett, E., J. Degan and J. Spiegel, Eds., Military Information Systems—The Design of Computer Aided Systems for Command, 180 p. (Frederick A. Praeger, Pub., New York, 1964).

Bennett, E., E. C. Haines and J. K. Summers, AESOP: A Prototype for On-Line User Control of Organizational Data Storage, Retrieval and Processing, AFIPS Proc. Fall Joint Computer Conf., Vol. 27, Pt. 1, Las Vegas, Nev., Nov. 30–Dec. 1, 1965, pp. 435–455 (Spartan Books, Washington, D.C., 1965).

Berul, L., Information Storage and Retrieval: A State-of-the-Art Report, Rept. No. PR–7500–145, 1 v. (Auerbach Corp., Philadelphia, Pa., Sept. 14, 1964).

Berul, L. H., Survey of IS & R Equipment, Datamation **14**, No. 3, 27–32 (Mar. 1968).

Bessinger, J. B., Jr., S. M. Parrish and H. F. Arader, Eds., Literary Data Processing Conference Proceedings, Sept. 9–11, 1964, 329 p. (IBM Corp., White Plains, N.Y., 1964).

*Additional references on page 124.

Bhimani, B. V., R. D. Merrill, R. P. Mitchell and M. R. Stark, An Approach to Speech Synthesis and Recognition on a Digital Computer, Proc. 21st National Conf., ACM, Los Angeles, Calif., Aug. 30–Sept. 1, 1966, pp. 275–296 (Thompson Book Co., Washington, D.C., 1966).

Blunt, C. R., An Information Retrieval System Model, Rept. No. 352, 14–R–1, 150 p. (HRB–Singer, Inc., State College, Pa., Oct. 1965).

Bobrow, D. G. and D. L. Murphy, Structure of a LIST System Using Two-Level Storage, Commun. ACM **10**, No. 3, 155–159 (March 1967).

Bobrow, D. G., R. Y. Kain, B. Raphael and J. C. R. Licklider, A Computer-Program System to Facilitate the Study of Technical Documents, Am. Doc. **17**, 186–187 (Oct. 1966).

Bohnert, H. G., English-Like Systems of Mathematical Logic for Content Retrieval, in Automation and Scientific Communication, Short Papers, Pt. 2, papers contributed to the Theme Sessions of the 26th Annual Meeting, Am. Doc. Inst., Chicago, Ill., Oct. 6–11, 1963, Ed. H. P. Luhn, pp. 155–156 (Am. Doc. Inst., Washington, D.C., 1963).

Bohnert, H. and M. Kochen, The Automated Multilevel Encyclopedia as a New Mode of Scientific Communication, in Some Problems in Information Science, Ed. M. Kochen, pp. 156–160 (The Scarecrow Press, Inc., New York, 1965).

Bones, W. L. and F. A. Kros, Nationwide Real-Time Warranty System, in Data Processing, Vol. X, Proc. 1966 International Data Processing Conf., Chicago, Ill., June 21–24, 1966, pp. 56–64 (Data Processing Management Assoc., 1966).

Bonn, T. H., Mass Storage; A Broad Review, Proc. IEEE **54**, 1861–1870 (Dec. 1966).

Borko, H., The Construction of an Empirically Based Mathematically Derived Classification System, Rept. No. SP–585, 23 p. (System Development Corp., Santa Monica, Calif., Oct. 26, 1961). Also in AFIPS Proc. Spring Joint Computer Conf., Vol. 21, San Francisco, Calif., May 13, 1962, pp. 279–289 (National Press, Palo Alto, Calif., 1962).

Borko, H., The Conceptual Foundations of Information Systems, Rept. No. SP–2057, 37 p. (System Development Corp., Santa Monica, Calif., May 6, 1965).

Borko, H., Integrating Computers into Behavioral Science Research, AFIPS Proc. Fall Joint Computer Conf., Vol. 27, Pt. 1, Las Vegas, Nev., Nov. 30–Dec. 1, 1965, pp. 527–532 (Spartan Books, Washington, D.C., 1965).

Borko, H. and H. P. Burnaugh, Interactive Displays for Document Retrieval, Rept. No. SP–2557, 25 p. (System Development Corp., Santa Monica, Calif., Aug. 4, 1966).

Bowers, D. M., Organization of Rotating Bulk Memories for Minimum Random Access Time, Computer Design **5**, No. 2, 40–44 (Feb. 1966).

Breuer, M. A., General Survey of Design Automation of Digital Computers, Proc. IEEE **54**, 1708–1721 (Dec. 1966).

Breuning, S. M. and T. N. Harvey, Implications of Integrated Transportation Engineering Design Systems for Computer Software and Hardware Development, Proc. 22nd National Conf., ACM, Washington, D.C., Aug. 29–31, 1967, pp. 255–262 (Thompson Book Co., Washington, D.C., 1967).

Brown, G. W., J. G. Miller and T. A. Keenan, Eds., EDUNET—Report of the Summer Study on Information Networks Conducted by the Interuniversity Communications Council (EDUCOM), 440 p. (Wiley, New York, 1967).

Brown, R. M., An Experimental Study of an On-Line Man-Computer System, IEEE Trans. Electron. Computers *EC–14*, 82–85 (1965).

Brown, S. C., A Bibliographic Search by Computer, Physics Today **19**, No. 5, 59–61, 63–64 (May 1966).

Brunelle, L. A., The Impact of Magazine Film Use in the Microfilm Industry, Eleventh Annual Meeting and Convention, Vol. XI, 1962, Ed. V. D. Tate, pp. 85–92 (The National Microfilm Assoc., Annapolis, Md., 1962).

Bryan, G. E., JOSS: 20,000 Hours at a Console—A Statistical Summary, AFIPS Proc. Fall Joint Computer Conf., Vol. 31, Anaheim, Calif., Nov. 14–16, 1967, pp. 769–777 (Thompson Books, Washington, D.C., 1967).

Bryant, E. C., Progress toward Evaluation of Information Retrieval Systems, in Information Retrieval Among Examining Patent Offices, Proc. Fourth Annual Meeting of the Committee for International Cooperation in Information Retrieval Among Examining Patent Offices, ICIREPAT, Washington, D.C., Oct. 7–16, 1964, Ed. H. Pfeffer, pp. 362–377 (Spartan Books, Washington, D.C., (1966).

Buck, C. P., R. F. Pray III and G. W. Walsh, Investigation and Study of Graphic-Semantic Composing Techniques, Rept. No. RADC–TR–61–58, Final Rept. Contract AF 30(602)2091, 1 v. (Syracuse Univ., Research Inst., June 1961).

Burchinal, L. G., The Expanding Role of Microforms in Education, NMA J. **1**, 2–6 (Fall 1967).

Burger, J. B., High Speed Display of Chemical Nomenclature, Molecular Formula and Structural Diagram, Rept. No. C105–R–4, 19 p. (General Electric Co., Huntsville, Ala., Dec. 31, 1964).

Burgess, E., Ed., On-Line Computing Systems, Proc. Symp. sponsored by the Univ. of California, Los Angeles, and Informatics, Inc., Los Angeles, Calif., Feb. 2–4, 1965, 152 p. (American Data Processing, Inc., Detroit, Mich., 1965).

Burkhardt, W. H., Universal Programming Languages and Processors: A Brief Survey and New Concepts, AFIPS Proc. Fall Joint Computer Conf., Vol. 27, Pt. 1, Las Vegas, Nev., Nov. 30–Dec. 1, 1965, pp. 1–21 (Spartan Books, Washington, D.C., 1965).

Burns, L. R., Automation in the Public Libraries of Lake County, Indiana, in Proc. 1963 Clinic on Library Applications of Data Processing, Univ. of Illinois, Apr. 28–May 1, 1963, Ed. H. Goldhor, pp. 9–17 (Graduate School of Library Science, Illinois Univ., Urbana, 1964).

Bushnell, D. D., Computer-Mediated Instruction—A Survey of New Developments, Computers & Automation **4**, 18–21 (Mar. 1965).

Calingaert, P., System Performance Evaluation: Survey and Appraisal, Commun. ACM **10**, 12–18 (Jan. 1967).

Carr, J. W., III and N. S. Prywes, Satellite Computers as Interpreters, Electronics **38**, No. 24, 87–89 (1965).

Carter, L. F., F. N. Marzocco, D. L. Drukey and C. Baum, Research and Technology Division Report for 1964, Rept. No. TM–530/008/00, 155 p. (System Development Corp., Santa Monica, Calif., Jan. 1965).

Chang, W., A Queuing Model for a Simple Case of Time Sharing, IBM Sys. J. **5**, No. 2, 115–125 (1966).

Chapman, G. A. and J. J. Quann, VISTA-Computed Motion Pictures for Space Research, AFIPS Proc. Fall Joint Computer Conf., Vol. 31, Anaheim, Calif., Nov. 14–16, 1967, pp. 59–63 (Thompson Books, Washington, D.C., 1967).

Chasen, S. H. and R. N. Seitz, On-Line Systems and Man-Computer Graphics, Computers & Automation **16**, 22–28 (Nov. 1967).

Cheydleur, B. F., SHIEF: A Realizable Form of Associative Memory, Am. Doc. **14**, No. 1, 56–67 (Jan. 1963).

Cheydleur, B. F., Ed., Colloquium on Technical Preconditions for Retrieval Center Operations, Proc. National Colloquium on Information Retrieval, Philadelphia, Pa., April 24–25, 1964, 156 p. (Spartan Books, Washington, D.C., 1965).

Cheydleur, B. F., Information Science and Liberal Education, Am. Doc. **16**, No. 3, 171–177 (July 1965).

Christensen, C. and E. N. Pinson, Multi-Function Graphics for a Large Computer System, AFIPS Proc. Fall Joint Computer Conf., Vol. 31, Anaheim, Calif., Nov. 14–16, 1967, pp. 697–711 (Thompson Books, Washington, D.C., 1967).

Christian, W. C., VSMF Stars in Microfilm Publishing, Systems **7**, No. 10, pp. 12–15, 42, 46 (Oct. 1966).

Clapp, V. W., Libraries and the 'Uppercase Limitation', in Libraries and Automation, Proc. Conf. held at Airlie Foundation, Warrenton, Va., May 26–30, 1963, under sponsorship of the Library of Congress, The National Science Foundation, and The Council on Library Resources, Ed. B. E. Markuson, pp. 54–55 (Library of Congress, Washington, D.C., 1964).

Clem, P. L., Jr., AMTRAN—A Conversational-Mode Computer System for Scientists and Engineers, in Proc. IBM Scientific Computing Symp. on Computer-Aided Experimentation, Yorktown Heights, N.Y., Oct. 11–13, 1965, pp. 115–150 (IBM Corp., White Plains, N.Y., 1966).

Climenson, W. D., File Organization and Search Techniques, in Annual Review of Information Science and Technology, Vol. 1, Ed. C. A. Cuadra, pp. 107–135 (Interscience Pub., New York, 1966).

366-108 O - 70 - 8

Clippinger, R. F., Programming Implications of Hardware Trends, IFIP Congress 65, Vol. 1, New York, N.Y., May 24–29, 1965, Ed. W. A. Kalenich, pp. 207–212 (Spartan Books, Washington, D.C., 1965).

Coffman, E., Stochastic Models of Multiple and Time-Shared Computer Operations, Ph. D. Dissertation, Dept. of Engineering, Univ. of California, Los Angeles, 1966.

Coffman, E. G. and B. Krishnamoorthi, Preliminary Analyses of Time-Shared Computer Operation, Rept. No. SP–1719 (System Development Corp., Santa Monica, Calif., Aug. 1964).

Coffman, E. G., Jr. and R. C. Wood, International Statistics for Time Sharing Systems, Commun. ACM **9**, No. 7, 500–503 (July 1966).

Coffman, E. G., Jr. and L. Kleinrock, Computer Scheduling Methods and Their Countermeasures, AFIPS Proc. Spring Joint Computer Conf., Vol. 32, Atlantic City, N.J., Apr. 30–May 2, 1968, pp. 11–21 (Thompson Book Co., Washington, D.C., 1968).

Coffman, E. G. and L. C. Varian, Further Experimental Data on the Behavior of Programs in a Paging Environment, Commun. ACM **11**, 471–474 (July 1968).

Coggan, B. B., The Design of a Graphic Display System, Rept. No. 67–36, 185 p. (Dept. of Engineering, Univ. of California, Los Angeles, Aug. 1967).

Cohen, J., A Use of Fast and Slow Memories in List-Processing Languages, Commun. ACM **10**, No. 2, 82–86 (Feb. 1967).

Cohen, J. B., G. O. Gardner and B. W. Romberg. Design Automation in Ship Detailing, Proc. 22nd National Conf., ACM, Washington, D.C., Aug. 29–31, 1967, pp. 341–353 (Thompson Book Co., Washington, D.C., 1967).

Coleman, A. H., R. F. Day and D. G. Gerlich, A Videocomp Systems Approach, in Electronic Composition in Printing, Proc. Symp. Gaithersburg, Md., June 15–16, 1967, NBS Special Pub. 295, Ed. R. W. Lee and R. W. Worral, pp. 29–36 (U.S. Govt. Printing Office, Washington, D.C., Feb. 1968).

Collila, R. A.. Time-Sharing and Multiprocessing Terminology, Datamation **12**, No. 3, 49–51 (March 1966).

Comfort, W. T., A Computing System Design for User Service, AFIPS Proc. Fall Joint Computer Conf., Vol. 27, Pt. 1, Las Vegas, Nev., Nov. 30–Dec. 1, 1965, pp. 619–626 (Spartan Books, Washington, D.C., 1965).

Computer Development (SEAC and DYSEAC) at the National Bureau of Standards, NBS Circular 551, 146 p. (Washington, D.C., Jan. 1955).

Condon, R. A., The Design of an Information Storage and Retrieval System: FMA's File Search, in Automation and Scientific Communication, Short Papers, Pt. 2, papers contributed to the Theme Sessions of the 26th Annual Meeting, Am. Doc. Inst., Chicago, Ill., Oct. 6–11, 1963, Ed. H. P. Luhn, pp. 137–138 (Am. Doc. Inst., Washington, D.C., 1963).

Connors, T. L., ADAM—A Generalized Data Management System, AFIPS Proc. Spring Joint Computer Conf., Vol. 28, Boston, Mass., April 1966, pp. 193–203 (Spartan Books, Washington, D.C., 1966).

Coons, S. A., An Outline of the Requirements for a Computer-Aided Design System, AFIPS Proc. Spring Joint Computer Conf., Vol. 23, Detroit, Mich., May 1963, pp. 299–304 (Spartan Books, Baltimore, Md., 1963).

Cooper, F. S., Haskins Laboratories: Research on Human Communication, Marine Ecology, and the Biochemistry of Protozoa, Science **158**, 1213–1215 (Dec. 1, 1967).

Cooper, W. W., H. J. Leavitt and M. W. Shelly II, Eds., New Perspectives in Organization Research (Wiley, New York, 1964).

Coordinated Science Laboratory, Univ. of Illinois, Progress Report for Dec. 1964, Jan. & Feb. 1965, Urbana, Ill., Apr. 7, 1965, 77 p.

Corbató, F. J., System Requirements for Multiple Access, Time-Shared Computers, Rept. No. MAC–TR–3, 14 p. (M.I.T., Cambridge, Mass., n.d.).

Corbató, F. J., The Transition from CTSS to MULTICS, Project MAC Progress Report III, pp. 95–101, 1967.

Corbin, H. S. and W. L. Frank, Display Oriented Computer Usage System, Proc. 21st National Conf., ACM, Los Angeles, Calif., Aug. 30–Sept. 1, 1966, pp. 515–526 (Thompson Book Co., Washington, D.C., 1966).

Cornew, R. W., A Statistical Method of Spelling Correction, Inf. & Control **12**, 79–93 (Feb. 1968).

Corrado, V. M., The Integration of Computers and High Speed Typesetting Into the Composing Room, in Automatic Typesetting, First International Technical Information Congress, La Compagine Francaise d' Editions, Paris, 1965, pp. 271–306.

Council on Library Resources, Inc., Tenth Annual Report for the period ending June 30, 1966, Washington, D.C., 1966, 128 p.

Critchlow, A. J., Generalized Multiprocessing and Multiprogramming, Proc. Fall Joint Computer Conf., Vol. 24, Las Vegas, Nev., Nov. 1963, pp. 107–126 (Spartan Books, Baltimore, Md., 1963).

Crowell, F. A. and S. C. Traegde, The Role of Computers in Instructional Systems: Past and Future, Proc. 22nd National Conf., ACM, Washington, D.C., Aug. 29–31, 1967, pp. 417–425 (Thompson Book Co., Washington, D.C., 1967).

Cuadra, C. A., A Feasibility Study for Automated Fingerprint Identification, Tech. Memo, TN–3007, 64 p. (System Development Corp., Santa Monica, Calif., 1966).

Cuadra, C. A., Ed., Annual Review of Information Science and Technology, Vol. 1, 389 p. (Interscience Pub., New York, 1966).

Cuadra, C. A., Ed., Annual Review of Information Science and Technology, Vol. 2, 484 p. (Interscience Pub., New York, 1967).

David, E. E., Jr., Sharing a Computer, Int. Sci. & Tech. **54**, 38–47 (1966).

Davis, R. M., Military Information Systems Design Techniques, in Military Information Systems—The Design of Computer-Aided Systems for Command, Ed. E. Bennett et al., pp. 19–28 (Frederick A. Praeger, Pub., New York, 1964).

Davis, R. M., Information Control in Command-Control Systems, in New Perspectives in Organization Research, Ed. W. W. Cooper et al., pp. 464–478 (Wiley, New York, 1964).

Davis, R. M., Classification and Evaluation of Information System Design Techniques, in Second Cong. on the Information System Sciences, held at The Homestead, Hot Springs, Va., Nov. 1964, Ed. J. Spiegel and D. E. Walker, pp. 77–83 (Spartan Books, Washington, D.C., 1965).

Davis, R. M., Man-Machine Communication, in Annual Review of Information Science and Technology, Vol. 1, Ed. C. A. Cuadra, pp. 221–254 (Interscience Pub., New York, 1966).

Day, M. S., The Scientific and Technical Information Program of the National Aeronautics and Space Administration, in U.S. Atomic Energy Commission, The Literature of Nuclear Science: Its Management and Use, Proc. Conf. held at Division of Technical Information Extension, Oak Ridge, Tenn., Sept. 11–13, 1962, pp. 361–377 (TID–7647, Oak Ridge, Tenn., 1962).

Denil, N. J., A Language and Model for Computer-Aided Design, Proc. 21st National Conf., ACM, Los Angeles, Calif., Aug. 30–Sept. 1, 1966, pp. 527–535 (Thompson Book Co., Washington, D.C., 1966).

Dennis, J. B., Segmentation and the Design of Multiprogrammed Computer Systems, J. ACM **12**, 589–602 (Oct. 1965).

Dennis, J. B. and E. L. Glaser, The Structure of On-Line Information Processing Systems, in Second Cong. on the Information System Sciences, held at The Homestead, Hot Springs, Va., Nov. 1964, Ed. J. Spiegel and D. E. Walker, pp. 5–14 (Spartan Books, Washington, D.C., 1965).

Dennis, J. B. and E. C. VanHorn, Programmed Semantics for Multiprogrammed Computations, Rept. No. MAC–TR–23, 46 p. (M.I.T., Cambridge, Mass., Dec. 1965).

DeParis, J. R., Random Access, Data Proc. Mag. **7**, 30–31 (Feb. 1965).

DeParis, J. R., Desk Top Teleprinter, Data Proc. Mag. **7**, No. 10, 48–49 (Oct. 1965).

Dertouzos, M. L., CIRCAL: On-Line Circuit Design, Proc. IEEE **55**, 637–654 (1967).

Diaz, A. J., Microreproduction Information Sources, Lib. Res. and Tech. Serv. **11**, No. 2, 210–214 (Spring 1967).

Diaz, A. J., On-Demand Publishing—The Clearinghouse Concept, in Levels of Interaction Between Man and Information, Proc. Am. Doc. Inst. Annual Meeting, Vol. 4, New York, N.Y., Oct. 22–27, 1967, pp. 238–241 (Thompson Book Co., Washington, D.C., 1967).

Dolby, J. L., L. L. Earl and H. L. Resnikoff, The Application of English-Word Morphology to Automatic Indexing and Extracting, Rept. No. M–21–65–1, 1 v. (Lockheed Missiles and Space Co., Palo Alto, Calif., April 1965).

Drew, D. L., R. K. Summit, R. I. Tanaka and R. B Whitely, An On-Line Technical Library Reference Retrieval System, in Information Processing 1965, Proc. IFIP Congress 65, Vol. 2, New York, N.Y., May 24–29, 1965, Ed. W. A. Kalenich, pp. 341–342 (Spartan Books, Washington, D.C., 1966). Also in Am. Doc. **17**, No. 1, 3–7 (Jan. 1966).
Dudley, H. W., The Vocoder, Bell Lab. Rec. **18**, 122–126 (1936).
Dugan, J. A., R. S. Green, J. Minker and W. E. Shindle, A Study of the Utility of Associative Memory Processors, Proc. 21st National Conf., ACM, Los Angeles, Calif., Aug. 30–Sept. 1, 1966, pp. 347–360 (Thompson Book Co., Washington, D.C., 1966).
Dumey, A. I., Considerations on Random and Sequential Arrangements of Large Numbers of Records, in Information Processing 1965, Proc. IFIP Congress 65, Vol. 1, New York, N.Y., May 24–29, 1965, Ed. W. A. Kalenich, pp. 255–260 (Spartan Books, Washington, D.C., 1965).
Duncan, C. J., Look! No Hands! in The Penrose Annual, A Review of the Graphic Arts, Vol. 57, pp. 121–167 (Hastings House, New York, 1964).
Duncan, C. J., General Comment, in Advances in Computer Typesetting, Proc. Int. Computer Typesetting Conf., Sussex, England, July 14–18, 1966, Ed. W. P. Jaspert, pp. x–xi (The Institute of Printing, London, 1967).
Dunning, A. W., Data Copy Dilemmas, Systems **6**, No. 6, 13–18 (1965).

Ebersole, J. L., North American Aviation's National Operating System, in Toward a National Information System, Second Annual National Colloquium on Information Retrieval, Philadelphia, Pa., April 23–24, 1965, Ed. M. Rubinoff, pp. 169–198 (Spartan Books. Washington, D.C., 1965).
Egbert, R. L., The Computer in Education: Malefactor or Benefactor, AFIPS Proc. Fall Joint Computer Conf., Vol. 24, Las Vegas, Nev., Nov. 1963, pp. 619–630 (Spartan Books, Baltimore, Md., 1963).
Eichelberger, E. B., W. C. Rodgers and E. W. Stacy, Method for Estimation and Optimization of Printer Speed Based on Character Usage Statistics, IBM J. Res. & Dev. **12**, 130–139 (Mar. 1968).
Engelman, C., MATHLAB: A Program for On-Line Machine Assistance in Symbolic Computations, AFIPS Proc. Fall Joint Computer Conf., Vol. 27, Pt. 1, Las Vegas, Nev., Nov. 30–Dec. 1, 1965, pp. 413–421 (Spartan Books, Washington, D.C., 1965).
Engvold, K. J. and J. L. Hughes, A Model for a Multifunctional Teaching System, Commun. ACM **10**, 339–342 (June 1967).
Estes, S. E., H. R. Kerby, H. D. Maxey and R. M. Walker, Speech Synthesis from Stored Data, IBM J. Res. & Dev. **8**, 2–12 (Jan. 1964).
Estrin, G. and L. Kleinrock, Measures, Models and Measurements for Time-Shared Computer Utilities, Proc. 22nd National Conf., ACM, Washington, D.C., Aug. 29–31, 1967, pp. 85–96 (Thompson Book Co., Washington, D.C., 1967).
Evans, D. C. and J. Y. Leclerc, Address Mapping and the Control of Access in an Interactive Computer, AFIPS Proc. Spring Joint Computer Conf., Vol. 30, Atlantic City, N.J., April 18–20, 1967, pp. 23–30 (Thompson Books, Washington, D.C., 1967).
Evans, D. S. and J. Katzenelson, Data Structure and Man-Machine Communication for Network Problems, Proc. IEEE **55**, 1135–1144 (July 1967).
Evans, T. G. and D. L. Darley, DEBUG—An Extension to Current Online Debugging Techniques, Commun. ACM **8**, 321–325 (May 1965).
Evans, T. G. and D. L. Darley, On-Line Debugging Techniques: A Survey, AFIPS Proc. Fall Joint Computer Conf., Vol. 29, San Francisco, Calif., Nov. 7–10, 1966, pp. 37–50 (Spartan Books, Washington, D.C., 1966).

Fano, R. M., The MAC System: A Progress Report, Rept. No. MAC-TR-12, 24 p. (M.I.T., Cambridge, Mass., Oct. 9, 1964).
Fano, R. M., The Computer Utility and the Community, 1967 IEEE Int. Conv. Rec., Pt. 12, pp. 30–37.
Fant, G., Acoustic Analysis and Synthesis of Speech with Applications to Swedish, reprint from Ericsson Technics No. 1, Sweden, 1959, 108 p.
Farrell, J., TEXTIR: A Natural Language Information Retrieval System, Tech. Memo. TM-2392, 37 p. (System Development Copr., Santa Monica, Calif., May 5, 1965).
Feingold, S. L., PLANIT—A Flexible Language Designed for Computer-Human Interaction, AFIPS Proc. Fall Joint Computer Conf., Vol. 31, Anaheim, Calif., Nov. 14–16, 1967, pp. 545–552 (Thompson Books, Washington, D.C., 1967).
Fiala, F. T., Time-Sharing Operations and Management, in Data Processing, Vol. X, Proc. 1966 Int. Data Processing Conf., Chicago, Ill., June 21–24, 1966, pp. 157–166 (Data Processing Management Assoc., 1966).
Fine, G. H., C. W. Jackson and P. V. McIsaac, Dynamic Program Behavior Under Paging, Proc. 21st National Conf., ACM, Los Angeles, Calif., Aug. 30–Sept. 1, 1966, pp. 223–228 (Thompson Book Co., Washington, D.C., 1966). Also in Rept. No. SP-2397, 19 p. (System Development Corp., Santa Monica, Calif., June 16, 1966).
Fisher, R. O. and C. D. Shepard, Time Sharing on a Computer with a Small Memory, Commun. ACM **10**, No. 2, 77–81 (Feb. 1967).
Five Compatible Computers from Honeywell, Data Proc. **7**, No. 5, 278–289 (Sept.–Oct. 1965).
Forgie, J. W., A Time- and Memory-Sharing Executive Program for Quick-Response On-Line Applications, AFIPS Proc. Fall Joint Computer Conf., Vol. 27, Pt. 1, Las Vegas, Nev., Nov. 30–Dec. 1, 1965, pp. 599–609 (Spartan Books, Washington, D.C., 1965).
Forte. A., Music and Computing: The Present Situation, AFIPS Proc. Fall Joint Computer Conf., Vol. 31, Anaheim, Calif., Nov. 14–16, 1967, pp. 327–329 (Thompson Books, Washington, D.C., 1967).
Franco, A. G., N. Marchand and L. J. Saporta, Error-Control Systems Get The Message Across, Electronics **38**, No. 23, 125–136 (1965).
Frank, W. L., On-Line CRT Displays: User Technology and Software, in On-Line Computing Systems, Proc. Symp. sponsored by the Univ. of California, Los Angeles, and Informatics, Inc., Feb. 1965, Ed. E. Burgess, pp. 50–62 (American Data Proc., Inc., Detroit, Mich., 1965).
Frey, H. C., C. E. Nelson and H. E. Rubin, A Line Density Standard to Replace Background Density, Proc. Eleventh Annual Meeting and Convention, Vol. XI, 1962, Ed. V. D. Tate, pp. 103–111 (The National Microfilm Assoc., Annapolis, Md., 1962).
Fubini, E. G., The Opening Address, in Second Cong. on the Information System Sciences, held at The Homestead, Hot Springs, Va., Nov. 1964, Ed. J. Spiegel and D. E. Walker, pp. 1–4 (Spartan Books, Washington, D.C., 1965).
Fuller, R. H., Content-Addressable Memory Systems, Rept. No. 63-25, 2 v. (Dept. of Engineering, Univ. of California, Los Angeles, 1963).
Fuller, R. H. and R. M. Bird, An Associative Parallel Processor with Application to Picture Processing, AFIPS Proc. Fall Joint Computer Conf., Vol. 27, Pt. 1, Las Vegas, Nev., Nov. 30–Dec. 1, 1965, pp. 105–116 (Spartan Books, Washington, D.C., 1965).

Gaines, R. S. and C. Y. Lee, An Improved Cell Memory, IEEE Trans. Electron. Computers *EC-14*, No. 1, 72–75 (Feb. 1965).
Gallenson, L., A Graphic Tablet Display Console for Use Under Time-Sharing, AFIPS Proc. Fall Joint Computer Conf., Vol. 31, Anaheim, Calif., Nov. 14–16, 1967, pp. 689–695 (Thompson Books, Washington, D.C., 1967).
Garvin, P. L., Ed., Natural Language and the Computer, 398 p. (McGraw-Hill, New York, 1963).
Gault, R. H. and G. W. Crane, Tactual Patterns from Certain Vowel Qualities Instrumentally Communicated from a Speaker to a Subject's Fingers, J. Gen. Psychol. **1**, 353–359 (1928).
Geddes, E. W., R. L. Emrich and J. F. McMurrer, Feasibility Report and Recommendations for New York State Identification and Intelligence System, Rept. No. TM-LO-1000/000/00, 276 p. (System Development Corp., Santa Monica, Calif., Nov. 1, 1963).
Gentle, E. C., Jr., Data Communications in Business, 163 p. (American Telephone and Telegraph Co., New York, 1965).
Gerlach, G. T., The Videograph Text Editor, in Electronic Composition in Printing, Proc. Symp., Gaithersburg, Md., June 15–16, 1967, NBS Special Pub. 295, Ed. R. W. Lee and R. W.

Worral, pp. 17–21 (U.S. Govt. Printing Office, Washington, D.C., Feb. 1968).
Gill, S., The Changing Basis of Programming, in Information Processing 1965, Proc. IFIP Congress 65, Vol. 1, New York, N.Y., May 24–29, 1965, Ed. W. A. Kalenich, pp. 201–206 (Spartan Books, Washington, D.C., 1965).
Gilman, W. L., Drum Scanning Techniques for Digitizing and Recording Image Data, 1966 IEEE Int. Conv. Rec., Pt. 3, pp. 29–38.
Giuliano, V. E., The Interpretation of Word Associations, in Statistical Association Methods for Mechanized Documentation, Symp. Proc., Washington, D.C., March 17–19, 1964, NBS Misc. Pub. 269, Ed. M. E. Stevens et al., pp. 25–32 (U.S. Govt. Printing Office, Washington, D.C., Dec. 15, 1965).
Gluck, S. E., Impact of Scratchpads in Design: Multifunctional Scratchpad Memories in the Burroughs B8500, AFIPS Proc. Fall Joint Computer Conf., Vol. 27, Pt. 1, Las Vegas, Nev., Nov. 30–Dec. 1, 1965, pp. 661–666 (Spartan Books, Washington, D.C., 1965).
Goldhor, H., Ed., Proceedings 1963 Clinic on Library Applications of Data Processing, Univ. of Illinois, Apr. 28–May 1, 1963, 176 p. (Graduate School of Library Science, Illinois Univ., Urbana, 1964).
Gomolak, L. S., Better and Faster Design by Machine, Electronics **37**, 64–71 (June 1964).
Greenberger, M., The Two Sides of Time-Sharing, Datamation **11**, 33–36 (Nov. 1965).
Gross, W. A., Information Storage and Retrieval, A State-of-the Art Report, Ampex READOUT, special issue, 9 p. (Ampex Corp., Redwood City, Calif., 1967).
Gunderson, D.C., W. L. Heimerdinger and J. P. Francis, Associative Techniques for Control Functions in a Multiprocessor, Rept. No. RADC–TR–66–573, 74 p. (Honeywell, Inc., Griffiss Air Force Base, N.Y., Dec. 1966).
Gurk, H. M. and J. Minker, The Design and Simulation of an Information Processing System, J. ACM **8**, 260–270 (1961).

Hamilton, M. L. and A. D. Weiss, An Approach to Computer-Aided Preliminary Ship Design, Rept. No. ESL–TM–228, 65 p. (Electronic Systems Lab., M.I.T., Cambridge, Mass., Jan. 1965).
Hanlon, A. G., Content-Addressable and Associative Memory System: A Survey, IEEE Trans. Electron. Computers *EC–15*, 509–521 (Aug. 1966).
Hanlon, A. G., W. C. Myers and C. O. Carlson, Photochromic Micro-Image Technology, A Review, paper presented at the Equipment Manual Symp., jointly sponsored by the American Ordnance Association and the Army Material Command, Detroit, Mich., Nov. 30–Dec. 2, 1965, 35 p. (The National Cash Register Co., Hawthorne, Calif., 1965).
Hargreaves, B., J. D. Joyce, G. L. Cole, E. D. Foss, R. G. Gray, E. M. Sharp, R. J. Sippel, T. M. Spellman and R. A. Thorpe, Image Processing Hardware for a Man-Machine Graphical Communication System, AFIPS Proc. Fall Joint Computer Conf., Vol. 26, San Francisco, Calif., Oct. 1964, pp. 363–386 (Spartan Books, Washington, D.C., 1964).
Harris, C. M., A Study of the Building Blocks in Speech, J. Acoust. Soc. Amer. **25**, 962 (1953).
Harrison, M. C. and J. T. Schwartz, SHARER, A Time-Sharing System for the CDC 6600, Commun. ACM **10**, 659–665 (Oct. 1967).
Hartsuch, P. J., Graphics Arts Progress . . . in 1967, Graphic Arts Monthly **40**, 52–57, 61 (Jan. 1968).
Haskins, S. M., Moving Toward International Cataloging Agreement, ALA Bull. **54**, 197–201 (1960).
Hattery, L. H. and G. P. Bush, Eds., Automation and Electronics in Publishing, derived from a Symposium sponsored by American Univ., held at Washington, D.C., May 1965, 206 p. (Spartan Books, Washington, D.C., 1965).
Hayes, R. M., Mathematical Models for Information Retrieval, in Natural Language and the Computer, Ed. P. L. Garvin, pp. 268–309 (McGraw-Hill, New York, 1963).
Heilprin, L. B., Communication Engineering Approach to Microforms, Am. Doc. **12**, No. 3, 213–218 (July 1961).
Herbert, E., Information Transfer, Int. Sci. & Tech. **51**, 26–37 (1966).
Hershey, A. V., Calligraphy for Computers, NWL Report No. 2101, 1 v. (U.S. Naval Weapons Lab., Dahlgren, Va., Aug. 1, 1967).
Hillegass, J. R., NCR's New Bid: The Century Series, Data Proc. Mag. **10**, No. 4, 46–49, 52–54 (Apr. 1968).
Hoadley, H. W., A Storage-Retrieval Display for Microfiche, in Progress in Information Science and Technology, Proc. Am. Doc. Inst. Annual Meeting, Bol. 3, Santa Monica, Calif., Oct. 3–7, 1966, pp. 29–34 (Adrianne Press, 1966).
Hoagland, A. S., Storing Computer Data, Int. Sci. & Tech. No. 37, 52–58 (Jan. 1965).
Hobbs, L. C., The Impact of Hardware in the 1970's, Datamation **12**, No. 3, 36–44 (Mar. 1966).
Hobbs, L. C., Display Applications and Technology, Proc. IEEE **54**, 1870–1884 (Dec. 1966).
Hogan, D. L., Speech as Computer Input and Output, 1966 IEEE International Convention Record, Vol. 14, Part 3, Computers, presented at IEEE Int. Conv., New York, N.Y., Mar. 21–25, 1966, pp. 91–93 (The Inst. of Electrical and Electronics Engineers, New York, 1966).
Holm, B. E., Techniques and Trends in Effective Utilization of Engineering Information, ASLIB Proc. **17**, 134–169 (1965).
Holt, A. W. (assignor to Control Data Corporation), Character Recognition Using Curve Tracing, U.S. Patent 3,142,818, issued July 28, 1964 (filed Feb. 21, 1961), 9 p.
Hormann, A. M., Introduction to ROVER, an Information Processor, Rept. No. FN–3487, 51 p. (System Development Corp., Santa Monica, Calif., Apr. 25, 1960).
Hornbuckle, G. D., A Multiprogramming Monitor for Small Machines, Commun. ACM **10**, No. 5, 273–278 (May 1967).
Howerton, P. W., The Application of Modern Lexicographic Techniques to Machine Indexing, in Machine Indexing: Progress and Problems, Proc. Third Institute on Information Storage and Retrieval, Washington, D.C., Feb. 13–17, 1961, pp. 326–330 (The American Univ., Washington, D.C., 1962).

IBM System/360, Data Proc. **7**, No. 5, 290–302 (Sept.–Oct. 1965).
Institute of Printing, Computer Type-Setting Conf., Report of Proc., London Univ., July 1964, 245 p. (Pub. London, 1965).
Israel, D. R., System Engineering Experience with Automated Command and Control Systems, in Information System Science and Technology, papers prepared for the Third Cong., scheduled for Nov. 21–22, 1966, Ed. D. E. Walker, pp. 193–213 (Thompson Book Co., Washington, D.C., 1967).
Iverson, J. and F. Yee, IBM's Flexible Addition to System 360, Electronics **38**, No. 24, 79–82 (1965).

Jaspert, W. P., Ed., Advances in Computer Typesetting, Proc. Int. Computer Typesetting Conf., Sussex, England, July 14–18, 1966, 306 p. (The Institute of Printing, London, 1967).
Johnson, L. R., On Operand Structure Representation, Storage, and Search, Rept. No. RC–603, 79 p. (Thomas J. Watson Research Center, Yorktown Heights, N.Y., Dec. 5, 1961).
Johnson, T. E., Sketchpad III: A Computer Program for Drawing in Three Dimensions, AFIPS Proc. Spring Joint Computer Conf., Vol. 23, Detroit, Mich., May 1963, pp. 347–353 (Spartan Books, Baltimore, Md., 1963).
Joyce, R. D. and S. Homa, Jr., High Speed Thermal Printing, AFIPS Proc. Fall Joint Computer Conf., Vol. 31, Anaheim, Calif., Nov. 14–16, 1967, pp. 261–267 (Thompson Books, Washington, D.C., 1967).
Just Merged: Copier and Computer, Bus. Automation **14**, No. 12, 50–51 (Dec. 1967).

Kalagher, J. J., Micromation—Its Impact on the Photocomposing Industry, in Electronic Composition in Printing, Proc. Symp., Gaithersburg, Md., June 15–16, 1967 NBS Special Pub. 295, Ed. R. W. Lee and R. W. Worral, pp. 37–39 (U.S. Govt. Printing Office, Washington, D.C., Feb. 1968).
Kalenich, W. A., Ed., Information Processing 1965, Proc. IFIP Congress 65, Vol. 1, New York, N.Y., May 24–29, 1965, 304 p. (Spartan Books, Washington, D.C., 1965).
Kalenich, W. A., Ed., Information Processing 1965, Proc. IFIP Congress 65, Vol. 2, New York, N.Y., May 24–29, 1965, pp. 305–648 (Spartan Books, Washington, D.C., 1966).
Kehl, W. B., Computers and Literature, Data Proc. Mag. **7**, 24–26 (July 1965).

Kehler, V. G., Conversion to Linotron, in Electronic Composition in Printing, Proc. Symp., Gaithersburg, Md., June 15–16, 1967, NBS Special Pub. 295, Ed. R. W. Lee and R. W. Worral, pp. 119–128 (U.S. Govt. Printing Office, Washington, D.C., Feb. 1968).

Kessler, M. M., The M.I.T. Technical Information Project I. System Description, 25 p. (The Libraries, M.I.T., Cambridge, Mass., Nov. 2, 1964).

King, D. W. and P. J. Terragno, Some Techniques for Measuring System Performance, in Parameters of Information Science, Proc. Am. Doc. Inst., Annual Meeting, Vol. 1, Philadelphia, Pa., Oct. 5–8, 1964, pp. 393–398 (Spartan Books, Washington, D.C., 1964).

King, G. W., The Library of Congress Project, Lib. Res. & Tech. Serv. **9**, No. 1, 90–93 (Winter 1965).

Kleinrock, L. Sequential Processing Machines (S.P.M.) Analyzed with a Queuing Theory Model, J. ACM **13**, No. 2, 179–193 (Apr. 1966).

Kleinrock, L. Theory of Queues and Time-Shared Computer Systems, 1966 IEEE Region Six Annual Conf. Record, Vol. II, pp. 491–500, 1966.

Kleinrock, L., Time-Shared Systems: A Theoretical Treatment, J. ACM **14**, No. 2, 242–261 (Apr. 1967).

Knauft, G., H. Lamparter and W. G. Spruth, Some New Methods for Digital Encoding of Voice Signals and for Voice Code Translation, IBM J. Res. & Dev. **10**, No. 3, 244–254 (May 1966).

Knowlton, K. C., A Computer Technique for Producing Animated Movies, AFIPS Proc. Spring Joint Computer Conf., Vol. 25, Washington, D.C., April 1964, pp. 67–87 (Spartan Books, Washington, D.C., 1964).

Kochen, M., Ed., Some Problems in Information Science, 309 p. (The Scarecrow Press, New York, 1965).

Kornblum, R. D., A Macro-View of Microfilm, Bus. Automation **12**, No. 10, 32–36 (Oct. 1965).

Kozumplik, W. A. and R. T. Lange, Computer-Produced Microfilm Library Catalog, Am. Doc. **18**, No. 2, 67–80 (April 1967).

Kraft, F. R., The Reduction in Bulk Resulting from the Typesetting of Documents in Modern Composition Systems, in Automation and Scientific Communication, Short Papers, Pt. 2, papers contributed to the Theme Sessions of the 26th Annual Meeting, Am. Doc. Inst., Chicago, Ill., Oct. 6–11, 1963, Ed. H. P. Luhn, pp. 275–276 (Am. Doc. Inst., Washington, D.C., 1963).

Krishnamoorthi, B. and R. C. Wood, Time-Shared Computer Operations with Both Inter-Arrival and Service Times Exponential, Rept. No. SP–2090 (System Development Corp., Santa Monica, Calif., Sept. 1965).

Kubert, B., J. Szabo and S. Giulieri, The Perspective Representation of Functions of Two Variables, J. ACM **15**, 193–204 (Apr. 1968).

Kuehler, J. D. and H. R. Kerby, A Photo-Digital Mass Storage System, AFIPS Proc. Fall Joint Computer Conf., Vol. 29, San Francisco, Calif., Nov. 7–10, 1966, pp. 735–742 (Spartan Books, Washington, D.C., 1966).

Kump, H. J. and P. T. Chang, Thermostrictive Recording on Permalloy Films, IBM J. Res. & Dev. **10**, No. 3, 255–260 (May 1966).

Lamberts, R. L. and G. C. Higgins, A System of Recording Digital Data on Photographic Film Using Superimposed Grating Patterns, AFIPS Proc. Fall Joint Computer Conf., Vol. 29, San Francisco, Calif., Nov. 7–10, 1966, pp. 729–734 (Spartan Books, Washington, D.C., 1966).

Lampson, B. W., A Scheduling Philosophy for Multiprocessing Systems, Commun. ACM **11**, No. 5, 347–360 (May 1968).

Landwehr, J. B., C. McLaughlin, H. Mueller, M. Lichstein and S. V. Pollack, BLNSYS—A 1401 Operating System with Braille Capabilities, Commun. ACM **8**, 300–303 (May 1965).

Lang, C. A., R. B. Polansky and D. T. Ross, Some Experiments with an Algorithmic Graphical Language, Rept. No. ESL–TM–220, 55 p. (M.I.T., Cambridge, Mass., Aug. 1965).

Langefors, B., State of the Art in Sweden, Data Proc. Mag. **7**, No. 5, 30–31 (1965).

Lannon, E. R., Computers and Composition in the U.S. Government—Past, Present and Future, in Advances in Computer Typesetting, Proc. Int. Computer Typesetting Conf., Sussex, England, July 14–18, 1966, Ed. W. P. Jaspert, pp. 80–84 (The Institute of Printing, London, 1967).

Lavington, S. H. and L. E. Rosenthal, Some Facilities for Speech Processing by Computer, The Computer J. **9**, 330–339 (Feb. 1967).

Lee, F. F., A Study of Grapheme to Phoneme Translation of English, Ph. D. Thesis in Electrical Engineering, 141 p. (M.I.T., Cambridge, Mass., 1966).

Lee, F. F., Machine-to-Man Communication by Speech Part 1: Generation of Segmental Phonemes from Text, AFIPS Proc. Spring Joint Computer Conf., Vol. 32, Atlantic City, N.J., Apr. 30–May 2, 1968, pp. 333–338 (Thompson Book Co., Washington, D.C., 1968).

Lee, M. O. and G. I. Campbell, Closing Session, Summary of Area Discussions, in National Academy of Sciences—National Research Council, Proc. Int. Conf. on Scientific Information, Vol. 2, Washington, D.C., Nov. 16–21, 1958, pp. 1549–1562 (NAS–NRC, Washington, D.C., 1959).

Lee, R. W. and R. W. Worral, Eds., Electronic Composition in Printing, Proc. Symp., Gaithersburg, Md., June 15–16, 1967, NBS Special Pub. 295, 128 p. (U.S. Govt. Printing Office, Washington, D.C., Feb. 1968).

Leiner, A. L., S. N. Alexander and R. P. Witt, DYSEAC, in Computer Development (SEAC and DYSEAC) at the National Bureau of Standards, Washington, D.C., NBS Circular 551, issued Jan. 25, 1955, pp. 39–71 (U.S. Govt. Printing Office, Washington, D.C., 1955).

LeVier, P. W., Computer-Aided Design of a Flip-Flop, Computer Design **4**, No. 11, 62–68 (1965).

Levine, L., J. B. Wiesner, O. H. Straus, B. Howland, N. Wiener and E. E. David, Jr., Felix (Sensory Replacement), Quarterly Progress Reports, Research Lab. of Electronics, Mass. Inst. of Technology, Jan. 1949–April 1951.

Levinthal, C., Computer Construction and Display of Molecular Models, in Proc. IBM Scientific Computing Symp. on Computer-Aided Experimentation, Yorktown Heights, N.Y., Oct. 11–13, 1965, pp. 315–325 (IBM Corp., White Plains, N.Y., 1966).

Levinthal, C., Molecular Model-Building By Computer, Sci. Amer. **214**, 42–52 (June 1966).

Lewin, M. H., H. R. Beelitz and J. Guarracini, Fixed Resistor-Card Memory, IEEE Trans. Electron. Computers *EC-14*, 428–434 (1965).

Lichtenberger, W. W. and M. W. Pirtle, A Facility for Experimentation in Man-Machine Interaction, AFIPS Proc. Fall Joint Computer Conf., Vol. 27, Pt. 1, Las Vegas, Nev., Nov. 30–Dec. 1, 1965, pp. 589–598 (Spartan Books, Washington, D.C., 1965).

Licklider, J. C. R., Libraries of the Future, 219 p. (M.I.T. Press, Cambridge, Mass., 1965).

Licklider, J. C. R., Man-Computer Interaction in Information Systems, in Toward a National Information System, Second Annual National Colloquium on Information Retrieval, Philadelphia, Pa., April 23–24, 1965, Ed. M. Rubinoff, pp. 63–75 (Spartan Books, Washington, D.C., 1965).

Licklider, J. C. R., Interactive Information Processing, in Computer and Information Sciences—II, Proc. 2nd Symp. on Computer and Information Sciences, Columbus, O., Aug. 22–24, 1966, Ed. J. T. Tou, pp. 1–13 (Academic Press, New York, 1967).

Licklider, J. C. R. and W. E. Clark, On-Line Man-Computer Communications, AFIPS Proc. Spring Joint Computer Conf., Vol. 21, San Francisco, Calif., May 1–3, 1962, pp. 113–128 (National Press, Palo Alto, Calif., 1962).

Lindgren, N., Human Factors in Engineering, Part I—Man in the Man-Made Environment, IEEE Spectrum **3**, No. 3, 132–139 (Mar. 1966).

Lock, K., Structuring Programs for Multiprogram Time-Sharing On-Line Applications, AFIPS Proc. Fall Joint Computer Conf., Vol. 27, Pt. 1, Las Vegas, Nev., Nov. 30–Dec. 1, 1965, pp. 457–472 (Spartan Books, Washington, D.C., 1965).

Loomis, H. H., Jr., Graphical Manipulation Techniques Using the Lincoln TX-2 Computer, Rept. No. 51–G–0017, 27 p. (Lincoln Lab., M.I.T., Lexington, Mass., Nov. 10, 1960).

Lourie, J. R., J. J. Lorenzo and A. Bomberault, On-Line Textile Designing, Proc. 21st National Conf., ACM, Los Angeles, Calif., Aug. 30–Sept. 1, 1966, pp. 537–544 (Thompson Book Co., Washington, D.C., 1966).

Loutrel, P., Determination of Hidden Edges in Polyhedral Figures: Convex Case, Rept. No. TR–400–145 (Laboratory

for Electroscience Research, New York Univ., New York, Sept. 1966).

Luhn, H. P., Ed., Automation and Scientific Communication, Short Papers, Pt. 2, papers contributed to the Theme Sessions of the 26th Annual Meeting, Am. Doc. Inst., Chicago, Ill., Oct. 6–11, 1963, pp. 129–352 (Am. Doc. Inst., Washington, D.C., 1963).

Lynch, W. C., Description of a High Capacity, Fast Turnaround University Computing Center, Commun. ACM **9**, 117–123 (Feb. 1966).

Machover, C., Graphic CRT Terminals—Characteristics of Commercially Available Equipment, AFIPS Proc. Fall Joint Computer Conf., Vol. 31, Anaheim, Calif., Nov. 14–16, 1967, pp. 149–159 (Thompson Books, Washington, D.C., 1967).

Mahan, R. E., A State of the Art Survey of the Data Display Field, Rept. No. BNWL–725, 1 v. (AEC Research and Development Report, Battelle Northwest, Richland, Wash., May 1968).

Manacher, G. K., Production and Stabilization of Real-Time Task Schedules, J. ACM **14**, No. 7, 439–465 (July 1967).

Marill, T. and L. G. Roberts, Toward a Cooperative Network of Time-Shared Computers, AFIPS Proc. Fall Joint Computer Conf., Vol. 29, San Francisco, Calif., Nov. 7–10, 1966, pp. 425–431 (Spartan Books, Washington, D.C., 1966).

Markuson, B. E., Ed., Libraries and Automation, Proc. Conf. held at Airlie Foundation, Warrenton, Va., May 26–30, 1963, 268 p., under sponsorship of the Library of Congress, the National Science Foundation, and the Council on Library Resources (Library of Congress, Washington, D.C., 1964).

Martin, D. and G. Estrin, Models of Computations and Systems-Evaluation of Vertex Probabilities in Graph Models of Computations, J. ACM **14**, No. 2, 281–299 (Apr. 1967).

Martin, W. A., A Step-by-Step Computer Solution of Three Problems in Non-Numerical Analysis, Project MAC Memo. M–323 (M.I.T., Cambridge, Mass., 1966).

Mathews, M. V. and J. E. Miller, Computer Editing, Typesetting and Image Generation, AFIPS Proc. Fall Joint Computer Conf., Vol. 27, Pt. 1, Las Vegas, Nev., Nov. 30–Dec. 1, 1965, pp. 389–397 (Spartan Books, Washington, D.C., 1965).

Mayeda, T., Methodology in Presentation, transcript of lecture delivered for the Institute of Management Sciences, Washington, D.C., Chapter, Nov. 1, 1967, 20 p.

Mayo, C. R., Electrostatic Printing Today and Tomorrow, in Research and Engineering Council of the Graphic Arts Industry, Proc. 14th Annual Conf., Rochester, N.Y., May 18–20, 1964, pp. 74–79 (Washington, D.C., 1964).

Mayzner, M. S. and M. E. Tresselt, Studies in Sequential Perception: Looking at One Thing But Finding Another, Perceptual and Motor Skills **23**, 257–258 (1966).

Mazzarese, N. J., Experimental System Provides Flexibility and Continuity, Data Proc. Mag. **7**, No. 5, 68–70 (1965).

McCarn, D. B., Large-Scale System Design Techniques, in Second Cong. on the Information System Sciences, held at The Homestead, Hot Springs, Va., Nov. 1964, Ed. J. Spiegel and D. E. Walker, pp. 95–98 (Spartan Books, Washington, D.C., 1965).

McCarthy, J., S. Boilen, E. Fredkin and J. C. R. Licklider, A Time-Sharing Debugging System for a Small Computer, AFIPS Proc. Spring Joint Computer Conf., Vol. 23, Detroit, Mich., May 1963, pp. 51–57 (Spartan Books, Baltimore, Md., 1963).

McCarthy, M. P., Generalized Graphic I/O: The Problem and an Approach, Data Proc. Mag. **9**, 64–65 (Nov. 1967).

McDonald, D. F., J. D. Freeman, C. B. Uzeta, and J. Dove, Dove Data Storage and Retrieval System, Rept. No RADC–TDR–64–307, 19 p. (Braddock, Dunn and McDonald, Inc., El Paso, Texas, Oct. 1964).

McDonald, R. F., Audio Response Unit Using a Digitally Stored Vocabulary, 1966 IEEE Int. Conv. Rec., Pt. 1, pp. 52–55.

McGee, W. C., On Dynamic Program Relocation, IBM Sys. J. **4**, No. 3, 184–199 (1965).

Melick, L. F., The Easy Way Out—and In, Data Proc. Mag. **9**, 42–46 (Mar. 1967).

Mergenthaler Linotype Co., Report on the Study and Investigation for the Design of a Lexical-Graphical Composer-Printer System, RADC–TDR–63–63, Final Rept. on Contract AF 30(602)2624, 1 v. (Brooklyn, N.Y., Jan. 31, 1963).

Microfilm Experts Scan the Future, Systems **8**, No. 1, 28–29 (Jan. 1967).

Mikhailov, A. I., Problems of Mechanization and Automation of Information Work, Rev. Int. Doc. **29**, 49–56 (1962).

Miller, J. C. and C. M. Wine, A Simple Display for Characters and Graphics, IEEE Trans. Computers *C–17*, 470–475 (May 1968).

Miller, J. R., On-Line Analysis for Social Scientists, Rept. No. MAC–TR–40, 25 p. (M.I.T., Cambridge, Mass., May 1967).

Mills, R. G., Man-Computer Interaction—Present and Future, 1966 IEEE Int. Conv. Rec., Pt. 6, pp. 196–198.

Mills, R. G., Man-Machine Communication and Problem Solving, in Annual Review of Information Science and Technology, Vol. 2, Ed. C. A. Cuadra, pp. 223–254 (Interscience Pub., New York, 1967).

Mills, R. G. and T. H. Van Vleck, Administrative Facilities and System Management, M.I.T. Project MAC Progress Report III, 1966, pp. 3–8.

Minker, J. and J. Sable, File Organization and Data Management, in Annual Review of Information Science and Technology, Vol. 2, Ed. C. A. Cuadra, pp. 123–160 (Interscience Pub., New York, 1967).

Mooers, C. N., Information Retrieval Selection Study. Part II: Seven System Models, Rept. No. ZTB–133, Part II, 39 p. (Zator Co., Cambridge, Mass., Aug. 1959).

Mooers, C. N., The Tape Typewriter Plan: A Method for Cooperation in Documentation, Rept. No. ZTB–137, 22 p. (Zator Co., Boston, Mass., July 1960). Also in ASLIB Proc. **12**, 277–291 (1960).

Mooers, C. N., An Emerging Revolution—The Reactive Typewriter, in Colloquium on Technical Preconditions for Retrieval Center Operations, Proc. National Colloquium on Information Retrieval, Philadelphia, Pa., April 24–25, 1964, Ed. B. F. Cheydleur, pp. 29–39 (Spartan Books, Washington, D.C., 1965).

Moore, R. T., M. C. Stark and L. Cahn, Digitizing Pictorial Information with a Precision Optical Scanner, Photogrammetric Engineering **30**, 923–931 (Nov. 1964).

Morenoff, E. and J. B. McLean, A Code for Non-Numeric Information Processing Applications in Online Systems, Commun. ACM **10**, No. 1, 19–22 (Jan. 1967).

Morey, J. L. and D. B. Yntema, Experiments on Systems, in Second Cong. on the Information System Sciences, held at The Homestead, Hot Springs, Va., Nov. 1964, Ed. J. Spiegel and D. E. Walker, pp. 349–368 (Spartan Books, Washington, D.C., 1965).

Morris, D., F. H. Sumner and M. T. Wyld, An Appraisal of the Atlas Supervisor, Proc. 22nd National Conf., ACM, Washington, D.C., Aug. 29–31, 1967, pp. 67–75 (Thompson Book Co., Washington, D.C., 1967).

Muerzeig, W., Towards More Versatile Teaching Machines, Computers & Automation **4**, 22–25 (Mar. 1965).

Neilsen, I. R., A Simple Data Transmission System Using the Office Telephone, Commun. ACM **8**, 634–635 (Oct. 1965).

Nelson, C. E., in System Magazine's Third Annual Microfilm Seminar, 1965, p. 39.

Nelson, T. H., Suggestions for an On-Line Braille Display, Proc. SID 6th National Symp. on Information Display, New York, N.Y., Sept. 29–30, 1965 (Western Periodicals Co., North Hollywood, Calif., 1965). Abstract in Inf. Display **2**, No. 5, 69 (Sept.–Oct. 1965).

New Mass Core Memory, Computer Design **4**, No. 6, 40–42 (June 1965).

The New Microfiche Standards, Systems **7**, No. 1, 35–36, 39 (Jan. 1966).

Nicholson, T. A. J. and R. D. Pullen, A Permutation Procedure for Job-Shop Scheduling, The Computer J. **11**, 48–56 (May 1968).

Ninke, W. H., Graphic 1—A Remote Graphical Display Console, AFIPS Proc. Fall Joint Computer Conf., Vol. 27, Pt. 1, Las Vegas, Nev., Nov. 30–Dec. 1, 1965, pp. 839–855 (Spartan Books, Washington, D.C., 1965).

Nisenoff, N., Hardware for Information Processing Systems: Today and in the Future, Proc. IEEE **54**, 1820–1835 (Dec. 1966).

Noll, A. M., Computer-Generated Three-Dimensional Movies, in Data Processing, Vol. X, Proc. 1966 Int. Data Processing

Conf., Chicago, Ill., June 21–24, 1966, pp. 143–148 (Data Processing Management Assoc., 1966).
Noll, A. M., Stereographic Projections by Digital Computer, in Data Processing, Vol. X, Proc. 1966 Int. Data Processing Conf., Chicago, Ill., June 21–24, 1966, pp. 149–156 (Data Processing Management Assoc., 1966).
Noll, A. M., A Computer Technique for Displaying *n*-Dimensional Hyperobjects, Commun. ACM **10**, 469–473 (Aug. 1967).

Ohlman, H., State-of-the-Art: Remote Interrogation of Stored Documentary Material, in Automation and Scientific Communication, Short Papers, Pt. 2, papers contributed to the Theme Sessions of the 26th Annual Meeting, Am. Doc. Inst., Chicago, Ill., Oct. 6–11, 1963, Ed. H. P. Luhn, pp. 193–194 (Am. Doc. Inst., Washington, D.C., 1963).
Opler, A., Dynamic Flow of Programs and Data Through Hierarchical Storage, in Information Processing 1965, Proc. IFIP Congress 65, Vol. 1, New York, N.Y., May 24–29, 1965, Ed. W. A. Kalenich, pp. 273–276 (Spartan Books, Washington, D.C., 1965).
Opler, A., Requirements for Real-Time Languages, Commun. ACM **9**, No. 3, 196–199 (Mar. 1966).
Oppenheimer, G. and N. Weizer, Resource Management for a Medium Scale Time-Sharing Operating System, Commun. ACM **11**, 313–322 (May 1968).
Orchard-Hays, W., Operating Systems for Job-to-Job Running and for Special Applications: Differences and Similarities, in Information Processing 1965, Proc. IFIP Congress 65, Vol. 1, New York, N.Y., May 24–29, 1965, Ed. W. A. Kalenich, pp. 237–242 (Spartan Books, Washington, D.C., 1965).
Ossorio, P. G., Dissemination Research, Rept. No. RADC–TR–65–314, 75 p. (Rome Air Development Center, Griffiss Air Force Base, New York, Dec. 1965).
O'Sullivan, T. C., Exploiting the Time-Sharing Environment, Proc. 22nd National Conf., ACM, Washington, D.C., Aug. 29–31, 1967, pp. 169–175 (Thompson Book Co., Washington, D.C., 1967).
Peele, D., Bind or Film: Factors in the Decision, Lib. Res. & Tech. Serv. **8**, 168–171 (Spring 1964).
Peirce, J. G. and W. B. Shannon, Interaction Between a Computerized Retrieval System and a Commercially Available Microfilm Cartridge File for Backup Data From Advance Locations, in Levels of Interaction Between Man and Information, Proc. Am. Doc. Inst. Annual Meeting, Vol. 4, New York, N.Y., Oct. 22–27, 1967, pp. 264–267 (Thompson Book Co., Washington, D.C., 1967).
Perry, M. N., Handling Very Large Programs, in Information Processing 1965, Proc. IFIP Congress 65, Vol. 1, New York, N.Y., May 24–29, 1965, Ed. W. A. Kalenich, pp. 243–247 (Spartan Books, Washington, D.C., 1965).
Peterson, R. M., New Techniques for Data Display, in Data Processing, Vol. X, Proc. 1966 Int. Data Processing Conf., Chicago, Ill., June 21–24, 1966, pp. 131–142 (Data Processing Management Assoc., 1966).
Pick, G. G. and D. B. Brick, A Read-Only Multi-Megahit Parallel Search Associative Memory, in Automation and Scientific Communication, Short Papers, Pt. 2, papers contributed to the Theme Sessions of the 26th Annual Meeting, Am. Doc. Inst., Chicago, Ill., Oct. 6–11, 1963, Ed. H. P. Luhn, pp. 245–246 (Am. Doc. Inst., Washington, D.C., 1963).
Pickett, J. M., Transmitting Speech Sounds by a Tactual Vocoder and by Lip-Reading, Rept. No. 27, 35 p. (The Speech Transmission Lab., Div. of Telegraphy-Telephony, The Royal Institute of Technology, Stockholm, Sweden, Mar. 1963).
Polland, C. B., Advanced Concepts of Utilization of Mass Storage, in Information Processing 1965, Proc. IFIP Congress 65, Vol. 1, New York, N.Y., May 24–29, 1965, Ed. W. A. Kalenich, pp. 249–254 (Spartan Books, Washington, D.C., 1965).
Porter, J. W. and L. E. Johnson, United Air Lines' Electronic Information System (EIS), in Data Processing, Vol. X, Proc. 1966 Int. Data Processing Conf., Chicago, Ill., June 21–24, 1966, pp. 74–82 (Data Processing Management Assoc., 1966).
Potter, R. J. and A. A. Axelrod, Optical Input/Output Systems for Computers, 1968 WESCON Technical Papers, 16/2, Aug. 1968, 6 p.
Press, L. I. and M. S. Rogers, IDEA — A Conversational, Heuristic Program for Inductive Data Exploration and Analysis, Proc. 22nd National Conf., ACM, Washington, D.C., Aug. 29–31, 1967, pp. 35–40 (Thompson Book Co., Washington, D.C., 1967).
Prince, M. D., Man-Computer Graphics for Computer-Aided Design, Proc. IEEE **54**, 1698–1708 (Dec. 1966).
Proctor, J. W., Jr., The Voice Response System, Datamation **12**, No. 8, 43–44 (Aug. 1966).
Prywes, N. S., A Storage and Retrieval System for Real-Time Problem Solving, Rept. No. 66–05, 47 p. (Moore School of Engineering, Univ. of Pennsylvania, Philadelphia, June 1, 1965).
Prywes, N. S., Executive and Retrieval Based Extended Machine, in Information Processing 1965, Proc. IFIP Congress 65, Vol. 2, New York, N.Y., May 24–29, 1965, Ed. W. A. Kalenich, pp. 460–461 (Spartan Books, Washington, D.C., 1966).
Prywes, N. S. and H. S. Gray, The Organization of a Multilist-Type Associative Memory, Commun. & Electronics **82**, 488–491 (1963).
Pyke, T. N., Jr., Computer Technology: A Forward Look, NBS Tech. News Bull. **51**, No. 8, 161–163 (Aug. 1967). Also in Yale Scientific, pp. 14–15, 28 Oct. 1967.

Rabiner, L., Speech Synthesis by Rule: An Acoustic Domain Approach, Bell Sys. Tech. J. **47**, 17–37 (Jan. 1968).
Ramamoorthy, C. V., The Analytic Design of a Dynamic Look Ahead and Program Segmenting System for Multiprogrammed Computers, Proc. 21st National Conf., ACM, Los Angeles, Calif., Aug. 30–Sept. 1, 1966, pp. 229–239 (Thompson Book Co., Washington, D.C., 1966).
Randell, B. and C. J. Kuehner, Dynamic Storage Allocation Systems, Commun. ACM **11**, No. 5, 297–306 (May 1968).
Reinfelds, J., L. A. Flenker, R. N. Seitz and P. L. Clem, Jr., AMTRAN, A Remote-Terminal, Conversational-Mode Computer System, Proc. 21st National Conf., ACM, Los Angeles, Calif., Aug. 30–Sept. 1, 1966, pp. 469–477 (Thompson Book Co., Washington, D.C., 1966).
Reiter, A., A Resource-Allocation Scheme for Multi-User On-Line Operation of a Small Computer, AFIPS Proc. Spring Joint Computer Conf., Vol. 30, Atlantic City, N.J., April 18–20, 1967, pp. 1–7 (Thompson Books, Washington, D.C., 1967).
Resnick, A., The 'Information Explosion' and the User's Need for Hard Copy, in Parameters of Information Science, Proc. Am. Doc. Inst. Annual Meeting, Vol. 1, Philadelphia, Pa., Oct. 5–8, 1964, pp. 315–317 (Spartan Books, Washington, D.C., 1964).
Richter, A. J., Z–39 Today: Its Work and Its Subcommittees, Spec. Lib. **54**, 107–109 (1963).
Riley, W. B., Time-Sharing: One Machine Serving Many Masters, Electronics **38**, No. 24, 72–78 (1965).
Rippy, D. E., D. E. Humphries and J. A. Cunningham, MAGIC — A Machine for Automatic Graphics Interface to a Computer, AFIPS Proc. Fall Joint Computer Conf., Vol. 27, Pt. 1, Las Vegas, Nev., Nov. 30–Dec. 1, 1965, pp. 819–830 (Spartan Books, Washington, D.C., 1965).
Risberg, A., Fundamental Frequency Tracking, Offprint, Proc. Int. Congress of Phonetic Sciences, 1961, pp. 228–231 (Mouton & Co.'s, Gravenhage, 1962).
Roberts, K. V., The Readability of Computer Programs, The Computer Bull. **10**, 17–24 (Mar. 1967).
Roberts, L. G., Graphical Communication and Control Languages, in Second Cong. on the Information System Sciences, held at The Homestead, Hot Springs, Va., Nov. 1964, Ed. J. Spiegel and D. E. Walker, pp. 211–217 (Spartan Books, Washington, D.C., 1965).
Roberts, L. G., Machine Perception of Three-Dimensional Solids, in Optical and Electro-Optical Information Processing, Ed. J. R. Tippett et al., pp. 159–197 (M.I.T. Press, Cambridge, Mass., 1965).
Rocchio, J. J., Possible Time-Sharing Organization for a SMART Retrieval System, in Information Storage and Retrieval, Scientific Rept. No. ISR–7, Ed. G. Salton, pp. XII–1 to XII–15 (Computation Lab., Harvard Univ., Cambridge, Mass., June 1964).
Rollert, D. H., The Linotron System, in Electronic Composition in Printing, Proc. Symp., Gaithersburg, Md., June 15–16, 1967, NBS Special Pub. 205, Ed. R. W. Lee and R. W. Worral, pp. 7–14, (U.S. Govt. Printing Office, Washington, D.C., Feb. 1968).

Rome Air Development Center, A Summary of the State-of-the-Art in Microfilm Document Storage and Retrieval Systems, Rept. No. RADC-TR-67-496, 114 p. (The Staff of Reconnaissance and Intelligence Data Handling Branch, Griffiss Air Force Base, N.Y., Sept. 1967).

Roos, D., An Integrated Computer System for Engineering Problem Solving, AFIPS Proc. Fall Joint Computer Conf., Vol. 27, Pt. 1, Las Vegas, Nev., Nov. 30–Dec. 1, 1965, pp. 423–433 (Spartan Books, Washington, D.C., 1965).

Rosa, J., Command Control Display Technology Since 1962, in Second Cong. on the Information System Sciences, held at The Homestead, Hot Springs, Va., Nov. 1964, Ed. J. Spiegel and D. E. Walker, pp. 411–414 (Spartan Books, Washington, D.C., 1965).

Ross, D. T. and J. E. Rodriguez, Theoretical Foundations for the Computer-Aided Design System, AFIPS Proc. Spring Joint Computer Conf., Vol. 23, Detroit, Mich., May 1963, pp. 305–322 (Spartan Books, Baltimore, Md., 1963).

Roudabush, G. E., C. R. T. Bacon, R. P. Briggs, J. A. Fierst, D. W. Isner and H. A. Nogun, The Left Hand of Scholarship: Computer Experiments with Recorded Text as a Communication Media, AFIPS Proc. Fall Joint Computer Conf., Vol. 27, Pt. 1, Las Vegas, Nev., Nov. 30–Dec. 1, 1965, pp. 399–411 (Spartan Books, Washington, D.C., 1965).

Rubinoff, M., Ed., Toward a National Information System, Second Annual National Colloquium on Information Retrieval, Philadelphia, Pa., April 23–24, 1965, 242 p. (Spartan Books, Washington, D.C., 1965).

Ruyle, A., J. W. Brackett and R. Kaplow, The Status of Systems for On-Line Mathematical Assistance, Proc. 22nd National Conf., ACM, Washington, D.C., Aug. 29–31, 1967, pp. 151–167 (Thompson Book Co., Washington, D.C., 1967).

Sackman, H., Time-Sharing versus Batch Processing: The Experimental Evidence, AFIPS Proc. Spring Joint Computer Conf., Vol. 32, Atlantic City, N.J., Apr. 30–May 2, 1968, pp. 1–10 (Thompson Book Co., Washington, D.C., 1968).

Salton, G., Ed., Information Storage and Retrieval, Scientific Rept. No. ISR-7, 1 v. (Computation Lab., Harvard Univ., Cambridge, Mass., June 1964).

Salton, G., An Evaluation Program for Associative Indexing, in Statistical Association Methods for Mechanized Documentation, Symp. Proc., Washington, D.C., March 17–19, 1964, NBS Misc. Pub. 269, Ed. M. E. Stevens et al., pp. 201–210 (U.S. Govt. Printing Office, Washington, D.C., Dec. 15, 1965).

Salton, G., The European Computer Gap, Commun. ACM **10**, No. 4, 203 (April 1967).

Samuel, A. L., Time-Sharing on a Multiconsole Computer, Rept. No. MAC-TR-17, 23 p. (M.I.T., Project MAC, Cambridge, Mass., Mar. 1965).

Sawyer, J. and M. F. Friedell, The Interaction Screen: An Operational Model for Experimentation on Interpersonal Behavior, Behav. Sci. **10**, 446–460 (1965).

Sayer, J. S., The Economics of a National Information System, in Toward a National Information System, Second Annual National Colloquium on Information Retrieval, Philadelphia, Pa., April 23–24, 1965, Ed. M. Rubinoff, pp. 135–146 (Spartan Books, Washington, D.C., 1965).

Scarrott, G. G., The Efficient Use of Multilevel Storage, in Information Processing 1965, Proc. IFIP Congress 65, Vol. 1, New York, N.Y., May 24–29, 1965, Ed. W. A. Kalenich, pp. 137–141 (Spartan Books, Washington, D.C., 1965).

Schatz, S., Facsimile Transmission in Libraries: A State of the Art Survey, Tech. Memo. No. 1, 24 p. (Information Systems Office, Library of Congress, Washington, D.C., June 1967).

Schecter, G., Ed., Information Retrieval—A Critical View, 282 p. (Thompson Book Co., Washington, D.C., 1967).

Scherr, A. L., An Analysis of Time-Shared Computer Systems, Ph. D. Dissertation, Rept. No. MAC-TR-18, 178 p. (M.I.T., Cambridge, Mass., June 1965).

Scholten, L. M., A Multiconsole Display Group for Use in an Information Retrieval System, in Colloquium on Technical Preconditions for Retrieval Center Operations, Proc. National Colloquium on Information Retrieval, Philadelphia, Pa., April 24–25, 1964, Ed. B. F. Cheydleur, pp. 125–131 (Spartan Books, Washington, D.C., 1965).

Schultz, C. K. and P. A. Schwartz, A Generalized Computer Method for Index Production, Am. Doc. **13**, No. 4, 420–432 (Oct. 1962).

Schwartz, J. I., E. G. Coffman and C. Weissman, Potentials of a Large-Scale Time-Sharing System, in Second Cong. on the Information System Sciences, held at The Homestead, Hot Springs, Va., Nov. 1964, Ed. J. Spiegel and D. E. Walker, pp. 15–32 (Spartan Books, Washington, D.C., 1965).

Schwartz, J. I. and C. Weissman, The SDC Time-Sharing System Revisited, Proc. 22nd National Conf., ACM, Washington, D.C., Aug. 29–31, 1967, pp. 263–271 (Thompson Book Co., Washington, D.C., 1967).

Schwelling, G., One View of the Standards, Systems **7**, No. 1, 36 (Jan. 1966).

Seehof, J. M., W. O. Evans, J. W. Friedericks and J. J. Quigley, Automated Facilities Layout Programs, Proc. 21st National Conf., ACM, Los Angeles, Calif., Aug. 30–Sept. 1, 1966, pp. 191–199 (Thompson Book Co., Washington, D.C., 1966).

Serlin, O., Automatic '3-D' Plotting with a Hybrid Computing System, Simulation **7**, 285–291 (1966).

Shalla, L., Automatic Analysis of Electronic Digital Circuits Using List Processing, Commun. ACM **9**, No. 5, 372–380 (May 1966).

Shaw, J. C., JOSS: A Designer's View of an Experimental On-Line Computing System, AFIPS Proc. Fall Joint Computer Conf., Vol. 26, San Francisco, Calif., Oct. 1964, pp. 455–464 (Spartan Books, Washington, D.C., 1964).

Shemer, J. E., Some Mathematical Considerations of Time-Sharing Scheduling Algorithms, J. ACM **14**, No. 2, 262–272 (April 1967).

Sherman, P. M., FLOWTRACE, A Computer Program for Flowcharting Programs, Commun. ACM **9**, No. 12, 845–854 (Dec. 1966).

Shiner, G., User Requirements, in Optical Character Recognition, Ed. G. L. Fischer, Jr., et al., pp. 335–338 (Spartan Books, Washington, D.C., 1962).

Silveira, H. M., Tele-Processing Terminals Offer User Wide Range of Applications Ability, Data Proc. Mag. **7**, No. 7, 36–39 (1965).

Silvern, G. M. and L. C. Silvern, Computer Assisted Instruction: Specification of Attributes for CAI Programs and Programmers, Proc. 21st National Conf., ACM, Los Angeles, Calif., Aug. 30–Sept. 1, 1966, pp. 57–62–5 (Thompson Book Co., Washington, D.C., 1966).

Silvern, G. M. and L. C. Silvern, Programmed Instruction and Computer-Assisted Instruction—An Overview, Proc. IEEE **54**, 1648–1655 (Dec. 1966).

Slade, A. E. and H. O. McMahon, A Cryotron Catalogue Memory System, Proc. Eastern Joint Computer Conf., Vol. 10, Theme: New Developments in Computers, New York, N.Y., Dec. 10–12, 1956, pp. 115–120 (American Inst. of Electrical Engineers, New York, 1957).

Soref, R. A. and D. H. McMahon, Bright Hopes for Display Systems: Flat Panels and Light Deflectors, Electronics **38**, No. 24, 56–62 (1965).

Souder, J. J., W. E. Clark, J. I. Elkind and M. B. Brown, Planning for Hospitals, 167 p. (Amer. Hospital Assoc., Chicago, Ill., 1964).

Sparks, D. E., L. H. Berul and D. P. Waite, Output Printing for Library Mechanization, in Libraries and Automation, Proc. of Conf. held at Airlie Foundation, Warrenton, Va., May 26–30, 1963, Ed. B. E. Markuson, pp. 155–190 (Library of Congress, Washington, D.C., 1964).

Spencer, H., Ed., The Penrose Annual, A Review of the Graphic Arts, Vol. 57, 300 p. (Hastings House, New York, 1964).

Spiegel, J. and D. E. Walker, Eds., Second Congress on the Information System Sciences, held at The Homestead, Hot Springs, Va., Nov. 1964, 525 p. (Spartan Books, Washington, D.C., 1965).

Stanga, D.C., Univac R 1108 Multiprocessor System, AFIPS Proc. Spring Joint Computer Conf., Vol. 30, Atlantic City, N.J., April 18–20, 1967, pp. 67–74 (Thompson Books, Washington, D.C., 1967).

Stevens, M. E., A Machine Model of Recall, in Information Processing, Proc. Int. Conf. on Information Processing, UNESCO, Paris, June 15–20, 1959, pp. 309–315 (Oldenbourg, Munich; Butterworths, London, 1960). Also preprint No. UNESCO/NS/ICIP/J. 54, 14 p.

Stevens, M. E., Nonnumeric Data Processing in Europe: A Field Trip Report, August–October 1966, NBS Tech. Note 462, 63 p. (U.S. Govt. Printing Office, Washington, D.C., Nov. 1968).
Stevens, M. E., V. E. Giuliano and L. B. Heilprin, Eds., Statistical Association Methods for Mechanized Documentation, Symp. Proc., Washington, D.C., March 17–19, 1964, NBS Misc. Pub. 269, 261 p. (U.S. Govt. Printing Office, Washington, D.C., Dec. 15, 1965).
Stevens, M.E. and J. L. Little, Automatic Typographic-Quality Composition Techniques: A State-of-the-Art Report, NBS Monograph 99, 98 p. (U.S. Govt. Printing Office, Washington, D.C., Apr. 7, 1967).
Stotz, R., Man-Machine Console Facilities for Computer-Aided Design, AFIPS Proc. Spring Joint Computer Conf., Vol. 23, Detroit, Mich., May 1963, pp. 323–328 (Spartan Books, Baltimore, Md., 1963).
Stotz, R. H., Directions in Time-Sharing Terminals, Computer Group News, IEEE **2**, 12–18 (May 1968).
Stowe, A. N. and D. B. Hampton, Speech Synthesis with Prerecorded Syllables and Words, J. Acoust. Soc. Amer. **33**, 810 (1961).
Stowe, A. N., R. A. Wiesen, D. B. Yntema and J. W. Forgie, The Lincoln Reckoner: An Operation-Oriented, On-Line Facility with Distributed Control, AFIPS Proc. Fall Joint Computer Conf., Vol. 29, San Francisco, Calif., Nov. 7–10, 1966, pp. 433–444 (Spartan Books, Washington, D.C., 1966).
Summit, R. K., DIALOG: An Operational On-Line Reference Retrieval System, Proc. 22nd National Conf., ACM, Washington, D.C., Aug. 29–31, 1967, pp. 51–56 (Thompson Book Co., Washington, D.C., 1967).
Sutherland, I. E., Sketchpad, A Man-Machine Graphical Communication System, AFIPS Proc. Spring Joint Computer Conf., Vol. 23, Detroit, Mich., May 1963, pp. 329–346 (Spartan Books, Baltimore, Md., 1963).
Sutherland, I. E., The Future of On-Line Systems, in On-Line Computing Systems, Proc. Symp. sponsored by the Univ. of California, Los Angeles, and Informatics, Inc., Feb. 1965, Ed. E. Burgess, pp. 9–13 (American Data Processing, Inc., Detroit, Mich., 1965).
Swanson, R. W., Information System Networks—Let's Profit from What We Know, in Information Retrieval—A Critical View, Ed. G. Shecter, pp. 1–52 (Thompson Book Co., Washington, D.C., 1967).
Systems Magazine's Third Annual Microfilm Seminar, Systems **6**, No. 8, 34–40 (Nov. 1965).

Tate, F. A., Handling Chemical Compounds in Information Systems, in Annual Review of Information Science and Technology, Vol. 2, Ed. C. A. Cuadra, pp. 285–309 (Interscience Pub., New York, 1967).
Tate, V. D., Ed., Proc. Eleventh Annual Meeting and Convention, Vol. XI, 1962, 360 p. (The National Microfilm Assoc., Annapolis, Md., 1962).
Tauber, A. S., Document Retrieval System Analysis and Design, in Progress in Information Science and Technology, Proc. Am. Doc. Inst. Annual Meeting, Vol. 3, Santa Monica, Calif., Oct. 3–7, 1966, pp. 273–281 (Adrianne Press, 1966).
Tauber, A. S. and W. C. Myers, Photochromic Micro-Images: A Key to Practical Microdocument Storage and Dissemination, Proc. Eleventh Annual Meeting and Convention, Vol. XI, 1962, Ed. V. D. Tate, pp. 257–269 (The National Microfilm Assoc., Annapolis, Md., 1962). Also in Am. Doc. **13**, No. 4, 403–409 (Oct. 1962).
Taylor, R. S., Professional Aspects of Information Science and Technology, in Annual Review of Information Science and Technology, Vol. 1, Ed. C. A. Cuadra, pp. 15–40 (Interscience Pub., New York, 1966).
Teitelman, W., PILOT: A Step Toward Man-Computer Symbiosis, Project MAC, Rept. No. MAC–TR–32, 193 p. (M.I.T., Cambridge, Mass., Sept. 1966).
Terlet, R. H., The CRT Display Subsystem of the IBM 1500 Instructional System, AFIPS Proc. Fall Joint Computer Conf., Vol. 31, Anaheim, Calif., Nov. 14–16, 1967, pp. 169–176 (Thompson Books, Washington, D.C., 1967).
Tippett, J. R., D. A. Berkowitz, L. C. Clapp, C. J. Koester and A. Vanderburgh, Jr., Eds., Optical and Electro-Optical Information Processing, 780 p. (M.I.T. Press, Cambridge, Mass., 1965).
Totschek, R. A., An Empirical Investigation into the Behavior of the SDS Time-Sharing System, Rept. No. SP–2191 (System Development Corp., Santa Monica, Calif., Aug. 1965).
Tou, J. T., Ed., Computer and Information Sciences—II, 2nd Symp. on Computer and Information Sciences, Columbus, O., Aug. 22–24, 1966, 368 p. (Academic Press, New York, 1967).
Travis, L. E., Analytic Information Retrieval, in Natural Language and the Computer, Ed. P. L. Garvin, pp. 310–353 (McGraw-Hill Book Co., New York, 1963).

Urbach, P., A Future Microsystem for the U.S. Patent Office, Proc. Eleventh Annual Meeting and Convention, Vol. XI, 1962, Ed. V. D. Tate, pp. 153–161 (The National Microfilm Assoc., Annapolis, Md., 1962).
Urquhart, A. B., Voice Output from IBM System/360, AFIPS Proc. Fall Joint Computer Conf., Vol. 27, Pt. 1, Las Vegas, Nev., Nov. 30–Dec. 1, 1965, pp. 857–865 (Spartan Books, Washington, D.C., 1965).

Van Dam, A. and J. C. Michener, Hardware Developments and Product Announcements, in Annual Review of Information Science and Technology, Vol. 2, Ed. C. A. Cuadra, pp. 187–222 (Interscience Pub., New York, 1967).
Veaner, A. B., Developments in Copying Methods and Graphic Communication 1965, Lib. Res. & Tech. Serv. **10**, 199–210 (Spring 1966).
Ver Hoef, E. W., Design of a Multi-Level File Management System, Proc. 21st National Conf., ACM, Los Angeles, Calif., Aug. 30–Sept. 1, 1966, pp. 75–86 (Thompson Book Co., Washington, D.C., 1966).
Vlahos, P., The Three-Dimensional Display: Its Cues and Techniques, Inf. Display **2**, No. 6, 10–20 (Nov.–Dec. 1965).
Vogel, N. A., Walnut Document Storage and Retrieval System, Proc. Eleventh Annual Meeting and Convention, Vol. XI, 1962, Ed. V. D. Tate, pp. 27–39 (The National Microfilm Assoc., Annapolis, Md., 1962).
Von Sydow, L., Computer Typesetting of ALGOL, Commun. ACM **10**, No. 3, 172–174 (Mar. 1967).

Wagner, F. V. and J. Granholm, Design of a General-Purpose Scientific Computing Facility, in Information Processing 1965, Proc. IFIP Congress 65, Vol. 1, New York, N.Y., May 24–29, 1965, Ed. W. A. Kalenich, pp. 283–289 (Spartan Books, Washington, D.C., 1965).
Walker, D. E., Ed., Information System Science and Technology—papers prepared for the Third Congress, scheduled for Nov. 21–22, 1966, 406 p. (Thompson Book Co., Washington, D.C., 1967).
Walker, D. E., SAFARI, An On-Line Text-Processing System, in Levels of Interaction Between Man and Information, Proc. Am. Doc. Inst. Annual Meeting, Vol. 4, New York, N.Y., Oct. 22–27, 1967, pp. 144–147 (Thompson Book Co., Washington, D.C., 1967).
Wall, H. and H. Falk, Circuit Analysis by Computer, Electro-Technology **78**, No. 5, 50–56 (1966).
Walter, C. J., Mathematical Techniques to Improve Hardware Accuracy of Graphic Display Devices, AFIPS Proc. Spring Joint Computer Conf., Vol. 30, Atlantic City, N.J., Apr. 18–20, 1967, pp. 107–120 (Thompson Books, Washington, D.C., 1967).
Walter, E. S. and V. L. Wallace, Further Analysis of a Computing Center Environment, Commun. ACM **10**, No. 5, 266–272 (May 1967).
Wang, W. S. Y. and G. E. Peterson, Segment Inventory for Speech Synthesis, J. Acoust. Soc. Amer. **30**, 743 (1958).
Wantman, M. E., CALCULAID: An On-Line System for Algebraic Computation and Analysis, Rept. No. MAC–TR–20 (thesis), 53 p. (M.I.T., Cambridge, Mass., Sept. 1965).
Ward, J. E., Systems Engineering Problems in Computer-Driven CRT Displays for Man-Machine Communication, IEEE Trans. Systems Sci. & Cybernetics SSC–3, 47–54 (June 1967).
Ware, W. H., Security and Privacy: Similarities and Differences, AFIPS Proc. Spring Joint Computer Conf., Vol. 30, Atlantic City, N.J., Apr. 18–20, 1967, pp. 287–290 (Thompson Books, Washington, D.C., 1967).
Webster, E., The Second Generation Line Printer, Data Proc. **7**, 42–43, 45 (1965).

Webster, E., Nonimpact Printout—What Is It? Where Is It Going? Data Proc. Mag. **8**, 32–33 (July 1966).
Wegner, P., Machine Organization for Multiprogramming, Proc. 22nd National Conf., ACM, Washington, D.C., Aug. 29–31, 1967, pp. 135–150 (Thompson Book Co., Washington, D.C., 1967).
Weil, J. W., The Impact of Time-Sharing on Data Processing Management, DPMA Q. **2**, No. 2, 2–16 (1966).
Weiss, R. A., Be VISION, A Package of IBM 7090 FORTRAN Programs to Draw Orthographic Views of Combinations of Plane and Quadric Surfaces, J. ACM **13**, No. 2, 194–204 (Apr. 1966).
Whiteman, I. R., New Computer Languages, Int. Sci. & Tech. **52**, 62–68 (1966).
Wigington, R. L., Graphics as Computer Input and Output, 1966 IEEE Int. Conv. Rec. Pt. 3, Computers, New York, N.Y., Mar. 21–25, 1966, pp. 86–90 (The Inst. of Electrical and Electronics Engineers, New York, 1966).
Wilkes, M. V., Slave Memories and Dynamic Storage Allocation, IEEE Trans. Electron. Computers *EC–14*, No. 2, 270–271 (April 1965).
Wilkes, M. V., The Design of Multiple-Access Computers Systems, The Computer J. **10**, 1–9 (May 1967).
Woodward, P. M., The Synthesis of Music and Speech, The Computer J. **9**, 257–262 (Nov. 1966).
Wooster, H., Towards a Uniform Federal Report Numbering System and a Cuddly Microfiche Reader—Two Modest Proposals, Rept. No. AFOSR–68–0772, 13 p. (Air Force Office of Scientific Research, Arlington, Va., Apr. 17, 1968).
Wylie, C., G. Romney, D. Evans and A. Erdahl, Half-Tone Perspective Drawings by Computer, AFIPS Proc. Fall Joint Computer Conf., Vol. 31, Anaheim, Calif., Nov. 14–16, 1967, pp. 49–58 (Thompson Books, Washington, D.C., 1967).

Yerkes, C. P., Microfiche, A New Information Media, in Automation and Scientific Communication, Short Papers, Pt. 2, papers contributed to the Theme Sessions of the 26th Annual Meeting, Am. Doc. Inst., Chicago, Ill., Oct. 6–11, 1963, Ed. H. P. Luhn, p. 129 (Am. Doc. Inst., Washington, D.C., 1963).
Yershóv, A. P., One View of Man-Machine Interaction, J. ACM **12**, No. 3, 315–325 (July 1965).

Additional References

Abrams, M. D., A Comparative Sampling of the Systems for Producing Computer-Drawn Flowcharts, Proc. 23rd National Conf., ACM, Las Vegas, Nev., Aug. 27–29, 1968, pp. 743–750 (Brandon/Systems Press, Inc., Princeton, N.J., 1968).

Baran, P., On Distributed Communications: IV. Priority, Precedence, and Overload, Research Memo. RM–3638–PR, 63 p. (The RAND Corp., Santa Monica, Calif., Aug. 1964).
Butler, E. J., Microfilm and Company Survival Plans, Proc. Eleventh Annual Meeting and Convention, Vol. XI, 1962, Ed. V. D. Tate, pp. 57–68 (The National Microfilm Assoc., Annapolis, Md., 1962).

Cantrell, H. N. and A. L. Ellison, Multiprogramming System Performance Measurement and Analysis, AFIPS Proc. Spring Joint Computer Conf., Vol. 32, Atlantic City, N.J., Apr. 30–May 2, 1968, pp. 213–221 (Thompson Book Co., Washington, D.C., 1968).
Chu, Y., A Destructive-Readout Associative Memory, IEEE Trans. Electron. Computers **EC–14**, No. 4, 600–605 (Aug. 1965).

Daley, R. C. and J. B. Dennis, Virtual Memory, Processes, and Sharing in MULTICS, Commun. ACM 11, No. 5, 306–312 (May 1968).
Davis, R. M., Information Control In An Information System, draft of lecture delivered to the Washington, D.C. Chapter, The Institute of Management Sciences, Oct. 18, 1967, 49 p.
Day, M. S., Application of Basic Principles in the Design and Operation of a Large Information System, in Toward a National Information System, Second Annual National Colloquium on Information Retrieval, Philadelphia, Pa., Apr. 23–24, 1965, Ed. M. Rubinoff, pp. 123–133 (Spartan Books, Washington, D.C., 1965).
Denning, P. J., The Working Set Model for Program Behavior, Commun. ACM **11**, No. 5, 323–333 (May 1968).

Fant, G., K. Fintoff, J. Liljencrants, B. Lindblom and J. Mártony, Formant-Amplitude Measurements, J. Acoust. Soc. Amer. **35**, 1753–1761 (1963).
Feige, E. L. and H. W. Watts, Partial Aggregation of Micro-Economic Data, 24 p. (Social Systems Research Institute, Univ. of Wisconsin, Madison, June 1967).
Fife, D. W. and R. S. Rosenberg, Queueing in a Memory Shared Computer, Proc. 19th National Conf., ACM, Philadelphia, Pa., Aug. 25–27, 1964, pp. H1–1 to H1–12 (Assoc. for Computing Machinery, New York, 1964).
Fikes, R. E., H. C. Lauer, and A. L. Vareha, Jr., Step Toward a General-Purpose Time-Sharing System Using Large Capacity Core Storage and TSS/360, Proc. 23d National Conf. ACM, Las Vegas, Nev., Aug. 27–29, 1965, pp. 7–18 (Braudon/Systems Press, Inc., Princeton, N.J., 1965).
Fleisher, A., P. Pengelly, J. Reynolds, R. Schools and G. Sincerbox, An Optically Accessed Memory Using the Lippman Process for Information Storage, in Optical and Electro-Optical Information Processing, Ed. J. R. Tippett et al., pp. 1–30 (M.I.T. Press, Cambridge, Mass., 1965).

Glauthier, T. J., Computer Time Sharing: Its Origins and Development, Computers & Automation **16**, 23–27 (Oct. 1967).
Gosden, J. A., The Operations Control Center MuH-Computer Operating System, Proc. 19th National Conf., ACM, Philadelphia, Pa., Aug. 25–27, 1964, pp. E2.2–1–E2.2–9 (Assoc. For Computing Machinery, New York, 1964).
Greenway, R. D. and M. V. Russell, Let's Design an Information System, p. 3 (preprint).

Haddon, B. K. and W. M. Waite, A Compaction Procedure for Variable-Length Storage Elements, The Computer J. **10**, 162–165 (Aug. 1967).
Harder, E. L., The Expanding World of Computers, Commun. ACM **11**, No. 4, 231–239 (Apr. 1968).
Haring, D. R., A Display Console for an Experimental Computer-Based Augmented Library Catalog, Proc. 23rd National Conf., ACM, Las Vegas, Nev., Aug. 27–29, 1968, pp. 35–43 (Brandon/Systems Press, Inc., Princeton, N.J., 1968).
Head, R. V., The Programming Gap in Real-Time Systems, Datamation **9**, 39–41 (Feb. 1963).
Hoagland, A. S., Mass Storage Revisited, Proc. 22nd National Conf., ACM, Washington, D.C., Aug. 29–31, 1967, pp. 255–260 (Thompson Book Co., Washington, D.C., 1967).
Holt, A. W., File Structure and the General Problem of Representation, Proc. IFIP Congress 65, Vol. 2, New York, N.Y., May 24–29, 1965, Ed. W. A. Kalenich, pp. 464–466 (Spartan Books, Washington, D.C., 1966).
Howerton, P. W., The Case for Realism in Document Storage Systems, Proc. Eleventh Annual Meeting and Convention, Vol. XI, 1962, Ed. V. D. Tate, pp. 21–25 (The National Microfilm Assoc., Annapolis, Md., 1962).
Hudson, D. M., The Applications and Implications of Large-Scale Integrations, Computer Design **7**, 38–42, 47–48 (June 1968).

Klerer, M., Final Report to the Advnced Research Projects Agency Computer Science Program, 33 p. (Hudson Labs., Columbia Univ., Dobbs Ferry, N.Y., Dec. 1, 1966).
Klerer, M. and J. May, Two-Dimensional Programming, AFIPS Proc. Fall Joint Computer Conf., Vol. 27, Pt. 1, Las Vegas,

Nev., Nov. 30–Dec. 1, 1965, pp. 63–75 (Spartan Books, Washington, D.C., 1965).
Kuipers, J. W., A. W. Tyler and W. L. Myers, A Minicard System for Documentary Information, Am. Doc. **8**, No. 4, 246–268 (Oct. 1957).

Landauer, W. I., The Balanced Tree and Its Utilization in Information Retrieval, IEEE Trans. Electron. Computers **EC–12**, 863–871 (Dec. 1963).
Laski, J. G., Segmentation and Virtual Address Topology—An Essay in Virtual Research, The Computer J. **11**, 35–40 (May 1968).
Linde, R. R. and P. E. Chaney, Operational Management of Time-Sharing Systems, Proc. 21st National Conf., ACM, Los Angeles, Calif., Aug. 30–Sept. 1, 1966, pp. 149–159 (Thompson Book Co., Washington, D.C., 1966).

McCormick, B. H., The Illinois Pattern Recognition Computer—ILLIAC III, IEEE Trans. Electron. Computers **EC–12**, 791–813 (Dec. 1963).
Mendelson, M. J. and A. W. England, The SDS SIGMA 7: A Real-Time Time-Sharing Computer, AFIPS Proc. Fall Joint Computer Conf., Vol. 29, San Francisco, Calif., Nov. 7–10, 1966, pp. 51–64 (Spartan Books, Washington, D.C., 1966).
Meadow, C. T., The Analysis of Information Systems: A Programmer's Introduction to Information Retrieval, 301 p. (Wiley, New York, 1967).

Pfeffer, H., Ed., Information Retrieval Among Examining Patent Offices, Proc. Fourth Annual Meeting of the Committee for International Cooperation in Information Retrieval Among Examining Patent Offices, ICIREPAT, Washington, D.C., Oct. 7–16, 1964, 627 p. (Spartan Books, Washington, D.C., 1966).
Pointel, N. and D. Cohen, Computer Time Sharing—A Review, Computers & Automation **16**, 38–46 (Oct. 1967).
Prywes, N. S., Man-Computer Problem Solving with Multilist, Proc. IEEE **54**, 1788–1801 (Dec. 1966).

Raphael, B., The Structure of Programming Languages, Commun. ACM **9**, No. 2, 67–71 (Feb. 1966).
Reich, A. and G. H. Dorion, Photochromic, High-Speed, Large Capacity, Semirandom Access Memory, in Optical and Electro-Optical Information Processing, Ed. J. R. Tippett et al., pp. 567–580 (M.I.T. Press, Cambridge, Mass., 1965).
Research on Archival Microfilm. NBS Tech. News Bull. **50**, No. 9, 154–155 (Sept. 1966).
Rosin, R. F., An Approach to Executive System Maintenance in Disk-Based Systems, The Computer J. **9**, 242–247 (Nov. 1966).

Smith, J. L., Multiprogramming under a Page on Demand Strategy, Commun. ACM **10**, No. 10, 636–646 (Oct. 1967).

Taube, M. and H. Wooster, Eds., Information Storage and Retrieval Theory, Systems and Devices, Air Force Office of Scientific Research Symp., Washington, D.C., 1958, 228 p. (Columbia Univ. Press, New York, 1958).
Taylor, R. S., The Process of Asking Questions, Am. Doc. **13**, No. 4, 391–396 (Oct. 1962).
Taylor, R. S., Question-Negotiation Seeking in Libraries, Rept. No. 3, Studies in the Man-System Interface in Libraries, 99 p. (Center for the Information Sciences, Lehigh Univ., Bethlehem, Pa., July 1967).

Wall, E., The Grouping and Arrangement of Terms, Items, and Their Codes, in Information Storage and Retrieval Theory, Systems and Devices, Air Force Office of Scientific Research Symp., Washington, D.C., 1958, Ed. M. Taube and H. Wooster, pp. 170–189 (Columbia Univ. Press, New York, 1958).
Wente, V. A., Specificity and Accessibility in a System of Information Centers on Space and Aeronautics, in Colloquium on Technical Preconditions for Retrieval Center Operations, Proc. National Colloquium on Information Retrieval, Philadelphia, Pa., Apr. 24–25, 1964, Ed. B. F. Cheydleur, pp. 55–60 (Spartan Books, Washington, D.C., 1965).
Wigington, R. L., A Machine Organization for a General Purpose List Processor, IEEE Trans. Electron. Computers **EC–12**, 707–714 (Dec. 1963).

U.S. GOVERNMENT PRINTING OFFICE : 1970 OL—366-108

NBS TECHNICAL PUBLICATIONS

PERIODICALS

JOURNAL OF RESEARCH reports National Bureau of Standards research and development in physics, mathematics, chemistry, and engineering. Comprehensive scientific papers give complete details of the work, including laboratory data, experimental procedures, and theoretical and mathematical analyses. Illustrated with photographs, drawings, and charts.

Published in three sections, available separately:

- **Physics and Chemistry**

Papers of interest primarily to scientists working in these fields. This section covers a broad range of physical and chemical research, with major emphasis on standards of physical measurement, fundamental constants, and properties of matter. Issued six times a year. Annual subscription: Domestic, $9.50; foreign, $11.75*.

- **Mathematical Sciences**

Studies and compilations designed mainly for the mathematician and theoretical physicist. Topics in mathematical statistics, theory of experiment design, numerical analysis, theoretical physics and chemistry, logical design and programming of computers and computer systems. Short numerical tables. Issued quarterly. Annual subscription: Domestic, $5.00; foreign, $6.25*.

- **Engineering and Instrumentation**

Reporting results of interest chiefly to the engineer and the applied scientist. This section includes many of the new developments in instrumentation resulting from the Bureau's work in physical measurement, data processing, and development of test methods. It will also cover some of the work in acoustics, applied mechanics, building research, and cryogenic engineering. Issued quarterly. Annual subscription: Domestic, $5.00; foreign, $6.25*.

TECHNICAL NEWS BULLETIN

The best single source of information concerning the Bureau's research, developmental, cooperative and publication activities, this monthly publication is designed for the industry-oriented individual whose daily work involves intimate contact with science and technology—*for engineers, chemists, physicists, research managers, product-development managers, and company executives.* Annual subscription: Domestic, $3.00; foreign, $4.00*.

*** Difference in price is due to extra cost of foreign mailing.**

NONPERIODICALS

Applied Mathematics Series. Mathematical tables, manuals, and studies.

Building Science Series. Research results, test methods, and performance criteria of building materials, components, systems, and structures.

Handbooks. Recommended codes of engineering and industrial practice (including safety codes) developed in cooperation with interested industries, professional organizations, and regulatory bodies.

Special Publications. Proceedings of NBS conferences, bibliographies, annual reports, wall charts, pamphlets, etc.

Monographs. Major contributions to the technical literature on various subjects related to the Bureau's scientific and technical activities.

National Standard Reference Data Series. NSRDS provides quantitive data on the physical and chemical properties of materials, compiled from the world's literature and critically evaluated.

Product Standards. Provide requirements for sizes, types, quality and methods for testing various industrial products. These standards are developed cooperatively with interested Government and industry groups and provide the basis for common understanding of product characteristics for both buyers and sellers. Their use is voluntary.

Technical Notes. This series consists of communications and reports (covering both other agency and NBS-sponsored work) of limited or transitory interest.

Federal Information Processing Standards Publications. This series is the official publication within the Federal Government for information on standards adopted and promulgated under the Public Law 89–306, and Bureau of the Budget Circular A–86 entitled, Standardization of Data Elements and Codes in Data Systems.

CLEARINGHOUSE

The Clearinghouse for Federal Scientific and Technical Information, operated by NBS, supplies unclassified information related to Government-generated science and technology in defense, space, atomic energy, and other national programs. For further information on Clearinghouse services, write:

Clearinghouse
U.S. Department of Commerce
Springfield, Virginia 22151

Order NBS publications from: Superintendent of Documents
Government Printing Office
Washington, D.C. 20402

U.S. DEPARTMENT OF COMMERCE
WASHINGTON, D.C. 20230

OFFICIAL BUSINESS

POSTAGE AND FEES PAID
U.S. DEPARTMENT OF COMMERCE